August 1955

NUCLEONICS

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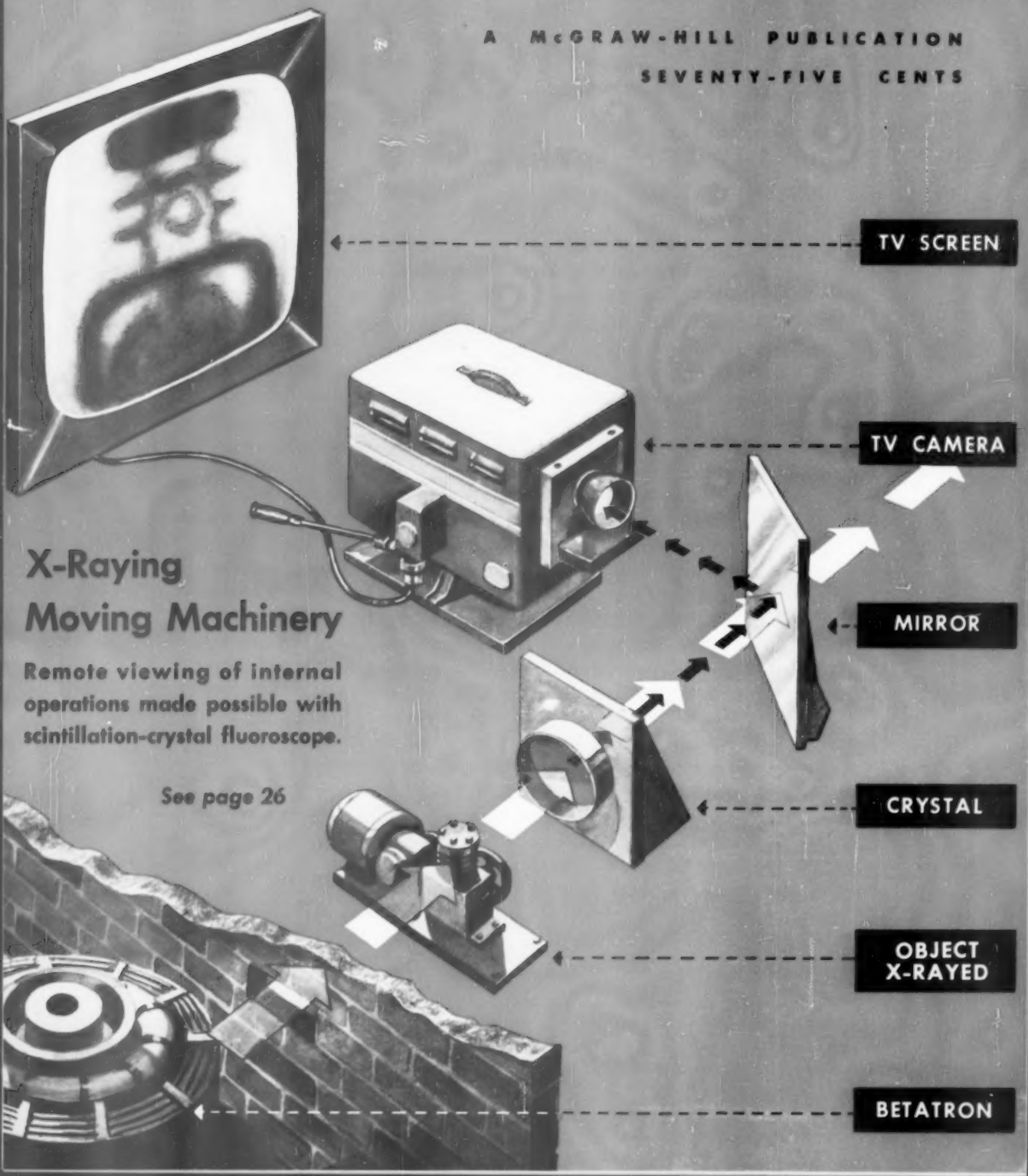

X-Raying Moving Machinery

Remote viewing of internal operations made possible with scintillation-crystal fluoroscope.

See page 26

Consolidated announces the

Evapor-ion

the first **dry** high-vacuum pump

Consolidated Vacuum Corporation announces a revolutionary new pump for producing high vacuum without organic or mercury fluids —the EVAPOR-ION—the only commercially available pump to create a "dry" vacuum in the pressure range from 10^{-4} to 10^{-9}mm Hg.

The EVAPOR-ION is the invention of Professor Ray Herb, Physics Department, University of Wisconsin. It is an electronically-operated device which entraps gas molecules through the combined application of metal evaporation and ion pumping, producing high pumping speeds, low ultimate pressures, and organic vapor-free operating conditions.

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Now available for sale is Consolidated's type 3161-01 EVAPOR-ION pump (twelve-inch nominal diameter casing) having a speed for nitrogen of 2,000 liters per second and 3,000 liters per second for hydrogen.

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Consolidated Vacuum Corporation, Rochester 3, New York (a subsidiary of Consolidated Engineering Corporation of Pasadena, California). Sales offices throughout the United States.

NUCLEONICS

AUGUST • 1955

Vol. 13, No. 8

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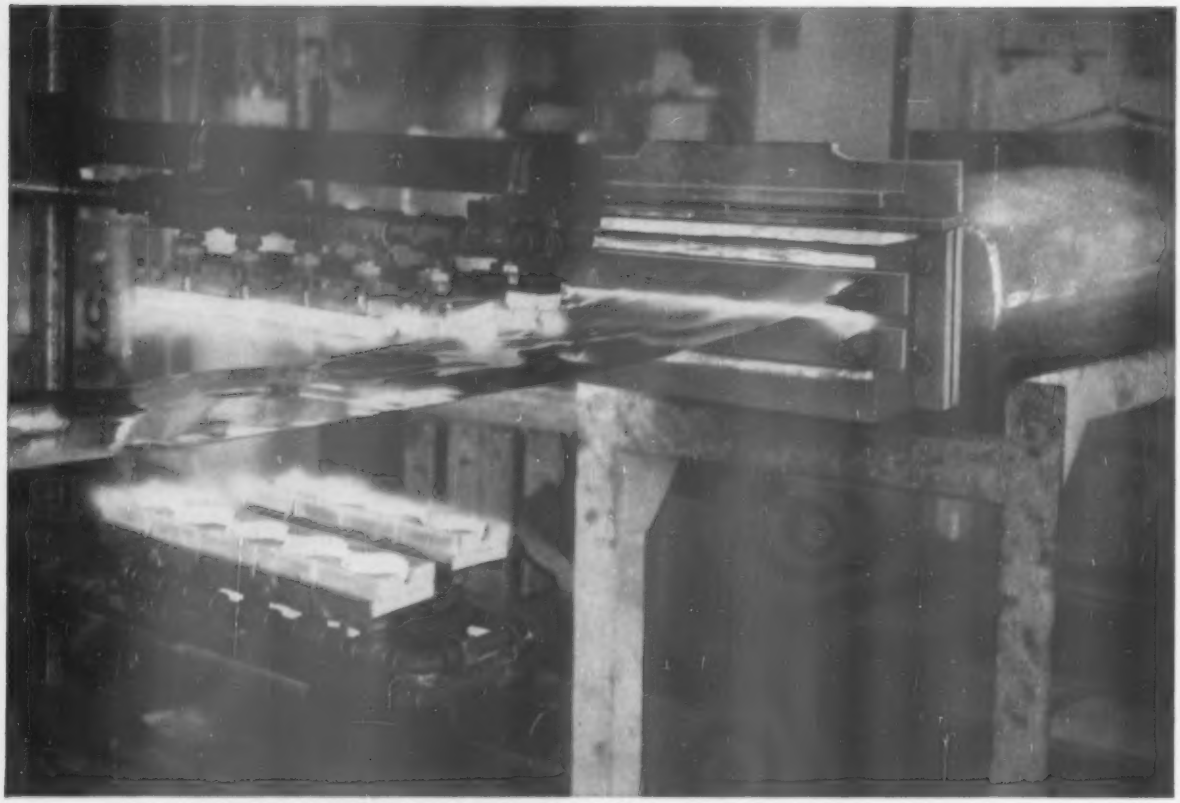

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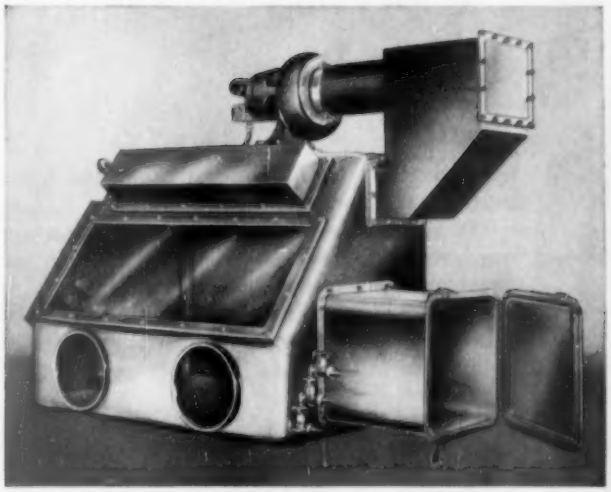

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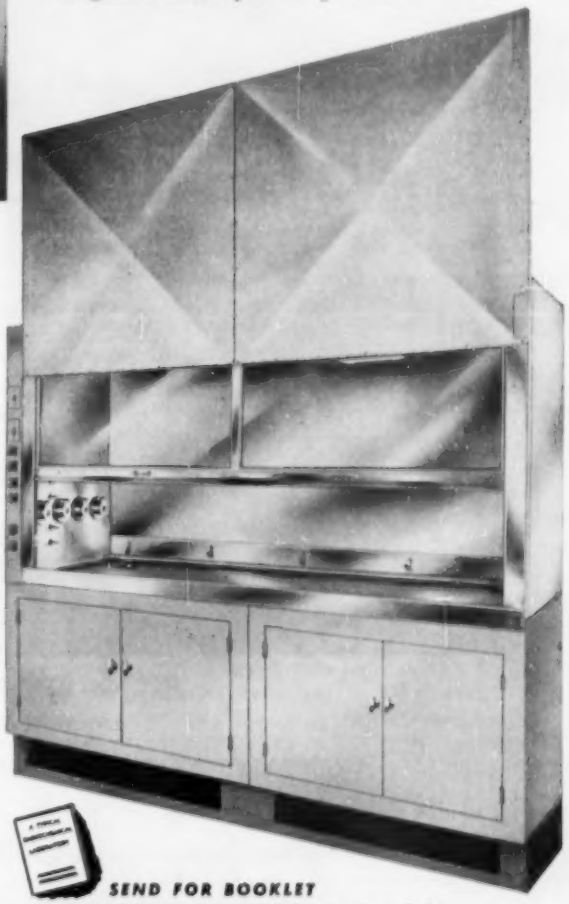

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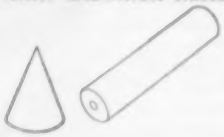

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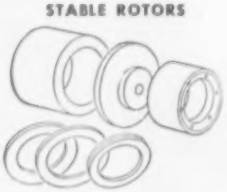

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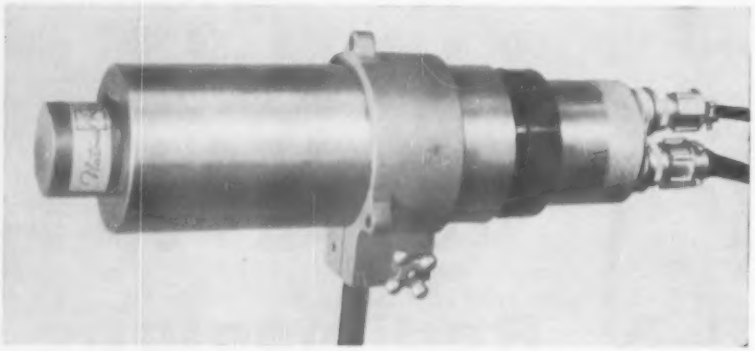


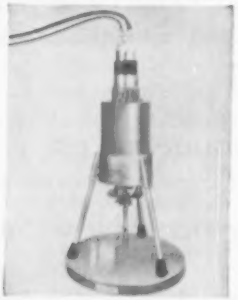
COLLIMATOR ATTACHMENT

Model LC-2 Collimator Attachment mounted on scintillation counter. Includes large, one-inch diameter by one-inch long sodium iodide crystal for high sensitivity. Highly directional lead shield in front and behind crystal insures low background. Convenient adjustable clamp and stand.

WELL TYPE SHIELD

Model LW-2 Shield Attachment holds scintillation counter and two-inch diameter well-type sodium iodide crystal. Provides full two inches of lead shielding in every direction, including below counter. Low background, high sensitivity. Crystal or counter instantly removable.

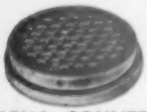
SAMPLE CHANGER



Model SM-2 Manual Sample Changer Attachment holds scintillation counter and crystal detectors. Provides two inches of lead shielding. Holds standard planchets.

A Complete Assortment of Crystal Radiation Detectors for Every Counting Need

Hermetically sealed, thin-walled containers. Optical glass windows. Transmits ultra violet. Interchangeable, permanent, light tight.



ALPHA COUNTER

Alpha particle counter. Light tight, insensitive to other radiations.

Hermetically sealed sodium iodide crystal. Best for gamma rays.

SODIUM IODIDE CRYSTAL

Sodium iodide, well type crystal. Has ¾ inch diameter by 1¼ inch deep well.

WELL TYPE CRYSTAL

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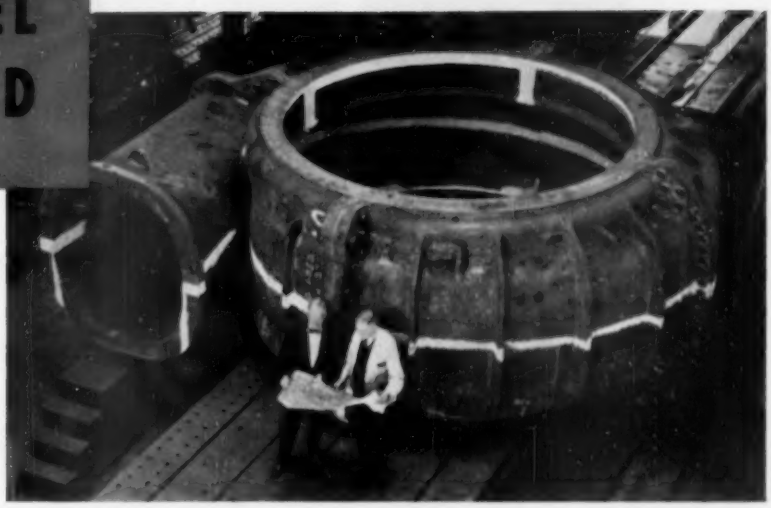
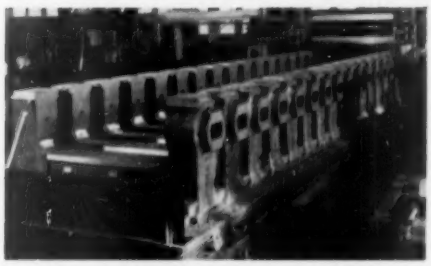
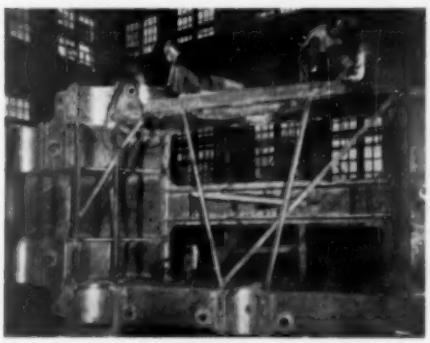


Meehanite water pump casing, cast in four parts, total weight 121,050 lbs.

to handle your casting, machining, welding



Planing rubber mill housings on 12-foot by 35-foot planer.



Welded assembly of steel plate and steel castings for rolling mill drive case.

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NDA_

The Board of Directors of

NUCLEAR DEVELOPMENT ASSOCIATES, INC.

announces a change in the name of the organization to

NUCLEAR DEVELOPMENT CORPORATION OF AMERICA

in keeping with its growing role as a major corporation in atomic energy and related fields.

The change is effective on August 1.

The change in name coincides with expansion into a new office and laboratory building at 5 New Street, White Plains, and the development of the 1200-acre Nuclear Experimental Station near Pawling in Dutchess County, N. Y.

NDA®—the Corporation will retain its familiar initials—gains administrative, engineering and laboratory space in its move from 18,000 square feet in four buildings to 55,000 square feet in a single building.

At the same time, planning is underway for the construction of a reactor "critical" facility at the Nuclear Experimental Station in Dutchess County. Future plans call for still further expansion of experimental facilities at Pawling.

We will be happy to meet with engineers and scientists interested in participating with ***NDA*** in this expanding field.

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ROUNDUP of Key Developments in Atomic Energy

LATE NEWS and Commentary

Foreign Developments

As this issue goes to press, the Geneva atomic energy conference is under way. With world-wide preoccupation with atomic matters, July saw important developments in several countries:

India. Government policy has been stated as follows: As in the steel sector so in nuclear development, India is prepared to examine offers for atomic assistance from any country provided there are no political strings attached. Economics will dictate what offers are accepted. The Government will build its own research reactors. The Trombay swimming-pool reactor, now under construction, is the first. Power reactors are still some way off. But the Government hopes to use British, French, UK, and U. S. knowhow to set these up during the next five years in such power-critical areas as the western India textile center of Ahmedabad and northwestern Rajasthan.

Holland. The bilateral agreement on atomic energy signed between the U. S. and Holland resulted in the formation last month of the Foundation Reactor Center Netherlands (RCN), in which virtually all Dutch atomic work will be centered. Cooperating in this group are: the Government, the Foundation for Fundamental Materials Research (FOM), KEMA (an electricity research center at Arnhem), and industry. The Government-appointed chairman is H. M. Hirschfield. Tentative plans call for an expenditure of $7.4-million with industry promising $1.6-million. As a result of the U. S. agreement the Dutch now plan to build a U. S.-type MTR. They also plan a uranium-oxide-suspension reactor (NU, Sept. '54, p. 16). Construction of both is expected to start next year.

Egypt. With equipment purchased from the U. S., this country is setting up its first radioisotope laboratory near Cairo. It will be used for medical diagnosis and treatment as well as for research. The lab is the first unit in a program being set up by the Egyptian Atomic Energy Commission.

Scandinavia. A proposal was made last month at a meeting in Copenhagen that a Nordic nuclear school be set up. . . . In addition to leasing uranium from the U. S., Denmark will buy uranium from England . . . Sweden's second reactor facility is expected to get the go-ahead signal from the Government on Atomenergi Aktiebolaget's request for $1.25-million. The plant will be located 50 miles southwest of Stockholm.

•

Reactor Information

In commenting last month on what the U. S. needs to do to demonstrate its sincerity in "atoms for peace," Sen. Clinton Anderson, (D., N. M.), chairman of the Joint Committee on Atomic Energy, said: "All reactor technology should be declassified . . . Folks in other countries may know just as much as we do and maybe more."

Strangely, Sen. Anderson feels differently on talking about U. S. work on thermonuclear reactors. He feels we don't know enough about the subject to discuss it. "Until we can define [the possibilities]," he says, "we shouldn't talk."

•

AEC Licenses

Including one that has been granted to Pennsylvania State University, AEC has received application for 14 licenses related to possession and use of fissionable material. Ten relate to construction and operation of reactors for industrial

and medical research and for production of electric power (Penn. State, Univ. of Michigan, UCLA, North Carolina State College, Armour Research Foundation, Battelle Memorial Institute, MIT, Naval Research Lab, Con Edison of N. Y., and Commonwealth Edison of Chicago); three are for licenses to possess and use special nuclear materials (Battelle, Nuclear Science and Eng. Corp., and Sylvania); and one proposes operation of a fuel-element fabrication facility (Metals and Controls Corp.).

•

Commonwealth Contracts with GE

Although AEC has not yet taken action on Commonwealth Edison Co.'s license application to build a 180,000-kw boiling reactor, the company has signed a contract with General Electric to build the plant for $45-million. It is expected that the actual plant cost will be considerably higher. Scheduled for completion by 1960, the facility will be paid for entirely with private funds.

Moving ahead quickly, GE announced at the same time that it is transferring five key men from its Hanford operations into a special staff for this project.

•

ETR Up in Air?

Although Kaiser Engineers has been awarded an architect-engineer contract by AEC on the Engineering Test Reactor, two private groups have come through with proposals to AEC for spending their own money on ETR-type plants. AEC has said it would not have a Government-owned reactor built if industry would do the job with its own funds.

The two proposals are: Babcock and Wilcox on a 50-50 basis with Lockheed Aircraft Corp., and the J. A. Jones Construction Co. of Charlotte, N. C. The B & W-Lockheed design is quite different from the present ETR concept and would be rated at 160 megawatts. It would also take much larger irradiation samples. Presumably, B & W would fabricate the metal parts and Lockheed would concern itself mostly with operation, experiments, etc.

•

Savannah River Cobalt

Space in the production reactors at Savannah River will be made available for the manufacture of cobalt-60 sources for teletherapy machines. It was recently predicted (NU, May '55, p. 10) that megacurie sources of cobalt could be produced in such reactors and that a typical source might contain 100–1,000 rods 1 inch in diameter by 1 foot. Cost was tagged at 15¢ per curie.

•

Gordon Dean Made General Dynamics V. P.

Gordon Dean, chairman of the Atomic Energy Commission from July, 1950 until June, 1953, has been elected senior vice president for nuclear energy of the General Dynamics Corporation. He has been a GD board member since July, 1954; he will remain an associate of Lehman Brothers, chairman of Nuclear Science and Engineering Corp., and director of Atomic Industrial Forum, Norden-Ketay Corp., and Fruehauf Trailer Co.

•

PP&L to Build Nuclear Plant

1962 is the "on-line" target for a 150-Mw nuclear power station to be built for Pennsylvania Power and Light Co. in the eastern part of the state. Westinghouse Electric Corp. has contracted to co-design and supply the homogeneous reactor and generating equipment. Private funds will finance the station, which is to be known as the Pennsylvania Advanced Reactor (PAR) Project. This is the sixth nuclear plant proposal made to AEC by the utility industry (NU, May '55, p. 11; July '55, p. 10).

West Considers Agency, Russia May Join

Now in its final stages of negotiation and revision, the draft of a treaty to be submitted to each of about eight charter members of an international atomic agency was revealed last month to be different in character from the structure of the organization envisaged by President Eisenhower in 1953. The proposal being considered will limit the positive functions of the agency at first to multilateral swapping of information and technical services, and educational features.

This draft is expected to be finalized and signed by the charter members by mid-August. When adopted and ratified by these, it will be offered for signing to prospective new member nations as their membership certificates.

One significant development that may change the character of the agency greatly was Russia's surprise offer last month to participate in the pool. For one thing, the organization presumably will be much larger than if Russia did not join, because other Eastern nations will come in with her, as will fence-sitting free nations which would otherwise be cautious about jumping into an organization which was obviously a Western club.

The draft treaty being looked at by the Western nations will contain these features:

- It will provide an international information and materials exchange program similar to that now in effect in this country. However, there will be no classified information or materials turned over to the UN. Each donor nation will retain control over these.
- The UN agency will not be responsible for physical custodianship of nuclear materials. As originally contemplated, the agency would receive from donor governments small amounts of nuclear fuels to be allocated among recipient nations from an international stockpile. Now, the concept involves giving the pool agency a somewhat limited allocation authority under which it can direct shipments from national stockpiles in donor countries. However, each nation would retain final say over such shipments.

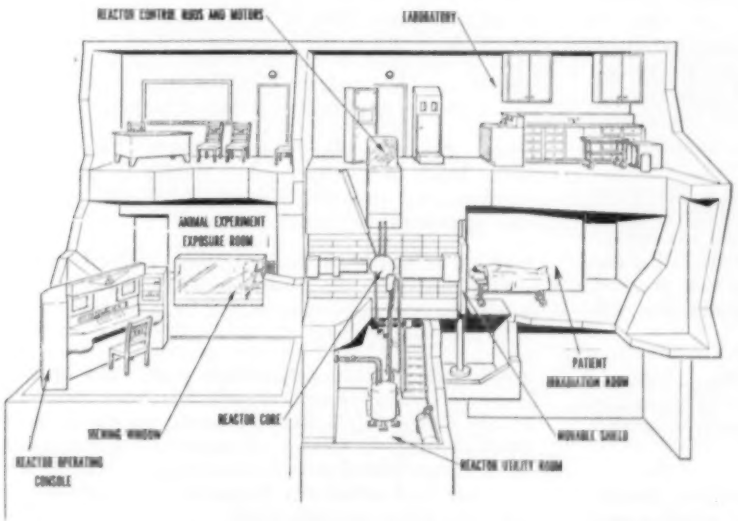
Even before the agency comes into being, there is at its disposal a minimum of 100 kilograms of special nuclear materials from this country. Eisenhower promised this when he first broached the atoms-for-peace plan. Since then, the U. S. has raised its offer of International aid to 200 kilos, but we've also entered into bilateral agreements with 27 individual nations, and these are eligible to share in our donation of fuels.

Britain, which has a bilateral agreement with us, has also offered fuel (20 kilos) for other nations, and will not draw from our donation.

- The agency will operate an unclassified library of technical information, and presumably will arrange for exchange of information on a bilateral basis, though this will not be spelled out in the treaty.
- Requirements for membership will be liberal. In fact, wording throughout is expected to be general, as much to allow for administrative discretion on the part of the UN agency running the pool, as to provide the smoothest possible sailing for the arrangement when each signatory takes it home for official approval.

There will be no most-favored-nation clause in the common treaty. This is designed to permit governments which are members of the pool to enter outside bilateral agreements without having to share automatically with pool members everything which is exchanged under those bilaterals. This nation, for instance, has individual bilateral agreements with Canada, Britain and Belgium, our World War II atomic development partners, which provide for exchange of classified information. We don't want to be obligated to share such information with all pool members.

U. S. officials report this country has been negotiating since last December—when the UN approved the idea—with Canada, Britain, France, Belgium, South Africa, Australia and Portugal, each of which has indicated it will join as soon as the draft treaty has been agreed on.



WORLD'S FIRST reactor specifically designed for medical treatment and research will be operating in about a year at U. of California at Los Angeles' medical center. Designed and built by North American Aviation, reactor will be a 5–50 kw self-contained water boiler developing 10^9 n/cm²/sec. Fuel will be in 4 gal of highly enriched uranyl sulphate solution in a 1-ft stainless-steel sphere. Design has stack of graphite 5 × 5 × 8 ft and 5-ft concrete shield surrounding core. Ports direct radiation to patient-treatment room, laboratory, and animal-exposure room; materials can be irradiated in a channel inside core. AEC will contribute $75,000 toward the $200,000 reactor, support extensive biomedical research program, and loan fuel; California Institute for Cancer Research so far has raised $79,000 of the balance. UCLA will house facility in a new $400,000 underground 45 × 60 × 27-ft building on the campus. Before clinical treatment of cancer begins, 2 years will be devoted to reactor calibration and development of safe techniques.

ROUNDUP

AEC Insurance Group Hopeful on Coverage

After four full months of studying radiation hazards and catastrophe potential of private atomic installations, a top-level insurance industry team is continuing its efforts to determine whether government support in underwriting liability insurance will be needed. Chances are they'll recommend legislation to set up such a federal program.

They indicated this in an interim report submitted in July to AEC. In that document, the 10-man group asked for more time to continue the study. AEC approved this request.

The insurance executives, from all types of underwriting concerns, stressed the difficulty of assessing the industry's ability to cover private atomic installations during a period of development which is experimental in nature.

As an "interim" conclusion, they found the industry could probably pool its resources to underwrite risks on the same basis as those in other hazardous industries are taken care of.

Here are some of the highlights of the group's report:

- Although remote, potential atomic catastrophe is the most serious thing yet encountered in industry.
- Insurance capacity for physical hazards of chemical operations seems adequate to cover reactor plants.
- However, if a reactor should be located close to large existing industrial plants, hazards to the other plants may be so great as to push needed coverage beyond the capacity of the insurance industry.
- Public liability hazards from reactors can be insured by existing insurance facilities up to the limits of liability normally available to more hazardous types of industrial enterprises.
- Insurance against loss of use frequently purchased in connection

Foreign News

South Africa exports U and Th. For the first four months of 1955, exports of these materials amounted to over $20-million as compared with $10-million for the same period last year. According to the latest estimates, annual production of U should be running about $110-million a year by 1957.

Venezuela to build nuclear center. Spurred by the signing of a bilateral agreement between the U. S. and Venezuela, the Institute of Neurology and Brain Disease Study at Caracas will build a special center for nuclear work in cooperation with UNESCO.

Cornerstone laid at CERN. The 12-nation European Organization for Nuclear Research is making progress in Geneva. At the time of the laying of the cornerstone for the laboratory last month, it was estimated that the 600-Mev synchrocyclotron will start operating in 1957 and that the mammoth 25-Bev proton synchrotron will be finished in 1960.

Dutch atomic exhibition. The Amsterdam, Holland, municipality and the Amsterdam chamber of commerce are planning to organize a major atomic energy exposition in Amsterdam in early 1957.

Canada to process own ores. For the first time, Canada now has facilities for processing its own uranium ores rather than having it done in the U. S. This will be done in a $2.5-million processing plant at Port Hope, Ontario, built by Catalytic Construction Co.

French expand program. It is now expected that France will spend nearly $300-million on her atomic program in the next three years. As part of this program, the French have obtained an agreement with the U. S. to buy 30 tons of heavy water for two research reactors. The sale will actually take place in the period 1956–58.

German reactor plans. Werner Heisenberg, head of German nuclear work, says his country will build two research reactors in the next four years.

ILO to work on nuclear problems. The International Labor Organization will embark on a program to: advise and assist in promoting the peaceful use of nuclear energy; study problems of adjustment that will arise in the fields of labor standards and working conditions from development of nuclear power; and promote the highest possible standards of health, safety and welfare among workers in plants using nuclear energy.

Korea, Peru, Sweden sign bilaterals. These three nation bring to 27 the number eligible to receive research reactor assistance from the U. S. They signed their agreements last month.

Australia to buy U. S. heavy water. Under an agreement signed with the Australian AEC, the U. S. will supply heavy water when needed for a nuclear reactor to be built near Sydney.

British industry moves into high gear. The Wolverhampton firm of John Thompson has been given the Atomic Energy Authority contract for supplying liquid metal circuits, the design of steam and water equipment, fusion-welded stainless steel vessels, primary and secondary heat exchangers, boiler drums, all instrumentation and a water treatment plant.

Head-Wrightson Processes Ltd., one of the participating firms in Britain's atomic program, has won a $2.1-million contract to build a heavy water research reactor in Australia (p. 15). Heavy water for this will come from New Zealand. Completion target is mid-'57. It's part of Australia's five-year $12-million nuclear development program.

Babcock & Wilcox Ltd. has gotten the contract to supply all three heat exchange systems—24 steam-raising towers of the Calder Hall type—for three additional dual-purpose (power plus plutonium) plants Britain will build immediately. Contract value is about $17-million.

with boiler damage insurance presents such a difficult insurance problem during early development of atomic power that if any such protection is available it will be limited.

- Physical damage losses to reactors and machinery can probably be handled in the same way that boiler coverage on extra-hazardous machinery is now handled in other industries.
- Workmen's compensation hazard for employees operating reactors and auxiliary equipment can be handled.
- The most serious problem as to the amount of insurance available lies in the field of third party liability insurance. Claims in event of atomic catastrophe might be made directly by the person suffering injury or arise as subrogation actions on the part of insurers called on to pay the loss in the first instance. They might be of catastrophic proportions.

Nevertheless, the committee had this to say of third-party liability: "Notwithstanding these complications, it is believed that the insurance industry can work out an aggregate limit of liability for all parties at interest substantially equivalent to those normally required by other major industrial enterprises."

It also had this hopeful note on all types of coverage: "As knowledge of the basic hazards involved increase, the insurance market should be expected to increase its capacity."

Japan Gets Set For Nuclear Work

With the initialling of the bilateral agreement on atomic energy with the United States, 6 kilograms of enriched uranium and technical assistance will be given to Japan, the Japanese Government and Japanese industry are moving into high gear to set up a structure to do atomic energy work.

At a meeting of the Government Committee for Investigation and Preparation for the Utilization of Atomic Energy last month, a policy was set whereby an atomic energy research institute would be established for the purpose of carrying out research and development in the field of atomic energy. Deliberation up to this date had centered on whether or not to delegate the execution of the nation's atomic

Washington Report

In its appearance before the Joint Committee on Atomic Energy to support its request for capital expenditures in 1956, AEC gave some interesting insight into its thinking and planning for the immediate future. Below are extracts from comments made by W. K. Davis, AEC's reactor chief, and W. F. Libby, AEC commissioner.

DAVIS: From studies of the demonstration proposals, in order for us to **process chemically** the types of fuel elements that the licensees and applicants are thinking about, we may have to make some additions or alterations to existing chemical processing plants.

DAVIS: The Detroit Edison group, in proposing a fast breeder, has asked the Commission to make what we call dynamic retrenchment studies of a **fast reactor core.** . . . We had thought $2-million . . . might be required to construct the facilities for carrying out the very difficult dynamic test of fast reactor cores.

AEC has indicated it may want to build a **10,000-kw small package power** plant later this year and that it would seek industry contributions to the project, perhaps on a basis similar to the Duquesne Light Co. deal on the PWR.

DAVIS: **Hot caves for making materials tests** are in short supply. Testing materials is a highly statistical business, and we have found so far that our work has required enormously large numbers of specimens and much greater range of variables than we had contemplated. . . . If large industrial contractors [don't jump in, we may have to build such facilities].

LIBBY: I was personally very disappointed to see that none of the proposals we received on April 1 included what I call the **chemical type of reactor** [homogeneous] which I believe is likely to give us the cheapest power, at least in large quantities at stationary power plants. I suppose that, if on the next go-around we still get nothing, I would be very strongly in favor of the Government's going ahead on its own.

DAVIS: EBR-II is about 40 times as large as EBR-I in terms of power output, and it is of the order of about $\frac{1}{16}$ the size of the so-called reference design, which was a **1,000 megawatt reactor.** And the problems in the fast breeder increase rather sharply as you increase the power, for the reason that in a fast reactor you have an exceedingly small core, and your central design and research problem is how to get a given amount of heat out of what would be very small space, and this is an exceedingly difficult job.

DAVIS: [in talking about the proposed **merchant ship reactor.**] We have never connected up two nuclear powerplants to a single propulsion shaft and this, of course, is a completely different requirement than any central station plant. . . . The control characteristics of this type of system are as yet unexplored. . . . The method of control of the reactor itself in terms of control systems and control elements, use of burnable poisons . . . will be markedly different.

ROUNDUP

energy program to universities, to the Electric Power Development (Public) Corporation or to a centralized agency.

This institute is to be an independent legal entity with an annual operating fund of an equivalent of approximately $½-million, coming mainly from donations from industry, loans and government subsidy.

The main functions of the institute will be to: receive shipments of enriched uranium from the U. S. and research reactors; administer and construct research reactors; carry out research with research reactors; and import, store and distribute radioisotopes. Temporary in nature this institute is to be developed into an authority or public corporation after such permanent structure has been fully thought out.

The actual shipment of enriched uranium and research reactors from the United States is expected to take place in the fall of 1956 since approval of the Japanese Legislature of the bilateral agreement can only be expected at the end of this year or next spring during the next session of the Legislature.

The Japanese Government has already made known that it will purchase from abroad two research reactors—a water-boiler type and possibly a swimming-pool type. After the first reactors have been imported the Government will probably build its own.

At the moment the Japanese Government has no definite plans on nuclear power although studies are being conducted. A regulatory body, similar to the U. S. A.E.C., is being deliberated upon in the Legislature, and a decision is expected to be reached soon.

Japanese industrial companies are also moving ahead, according to Radio Tokyo.

With Hitachi, Ltd., as the pioneer in the field, leading Japanese firms have already concluded technical agreements with major American firms engaged in industrialization of atomic energy. The Hitachi firm last fall formed an atomic energy research committee within the company in preparation for the building of various types of atomic reactors. After completing blueprints on various types of reactors, the company is slated to ask the government for a research subsidy. Hitachi is planning to purchase parts which cannot be produced in Japan at the present stage from the United States.

The Tokyo-Shibaura Electric Company, which has concluded a technical contract with the General Electric Company, has already received research funds from the government. The funds are for research on construction of manipulators for handling radioactive materials and radioactive counters on a trial basis. In the future, the company is expected to become the leading Japanese maker of manipulators and counters.

The Showa Denko Company is already pushing plans to manufacture heavy water by utilizing 4,800 electrolytic tanks used for making ammonium sulfate. Under present know-how, 2% heavy water can be made in Japan, but the company is confident that heavy water of nearly 100% will be produced when electrolytic tanks at its Kawasaki plant are operated fully. It believes two to three tons could be produced annually at about 100 yen per gram in the future.

Reactor News

Stone & Webster to start APPR construction next month. Alco Products, Inc. announced last month that Stone & Webster Engineering Corp., architect-engineers for the PWR project at Shippingport, Pa., has been selected to serve in a similar capacity on the Army Package Power Reactor project (NU, Jan. '55, p. 76; May '55, p. 24). With initial construction expected in September, the plant is scheduled to operate in 1957.

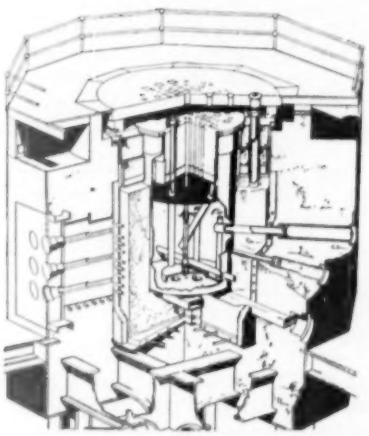
30 U. S. universities considering research reactors. After a survey of 103 members of the Engineering College Research Council, H. S. Isbin told the American Society of Engineering Education that 30 institutions are planning to acquire reactors for use in their educational and research programs. One, North Carolina State College, has a reactor in operation. Illinois Institute of Technology, U. of Michigan, and Pennsylvania State College have reactors under construction. In the advanced planning stage are: Alabama Polytechnic Institute, Massachusetts Institute of Technology, Vanderbilt University, Washington State College, and the Universities of California at Los Angeles (see picture on page 11 for later development), Florida, and Utah. In the initial-thinking stage are: Columbia, Cornell, Northwestern, Ohio State, and Purdue Universities, Iowa State and Kansas State Colleges, Case and Georgia Institutes of Techonology, A. & M. College of Texas, and the Universities of Arkansas, California (Berkeley), Colorado, Connecticut, Denver, Illinois, Missouri, Southern California, and Texas.

Britain looks for Geneva orders to start $5-billion flow of nuclear exports over next 20 years. While the British government and firms ready a big push at Geneva to launch export trade in nuclear equipment, a new $68-million program involving three twin-reactor plutonium-producing Calder-Hall-type power plants has been started. This is in addition to Britain's $840-million 10-yr power-reactor program (NU, March '55, p. 7; April '55, p. 9). The Atomic Energy Authority is keeping a monopoly on weapons, fuel manufacture and processing, and radioisotopes, but all other aspects are open to industry. The Government's training, fuel pricing, and patents policies are designed to encourage industrial nuclear development. AEA patents normally are available on a 5% royalty basis; company-developed patents will be owned by the firms in the usual manner. At least one firm is spending $6.5-million this year on nuclear research—many others are sharply stepping up nuclear development with an eye to early sales to West Europe and the Commonwealth. For more details on British industry efforts, see p. 12.

The Asahi Synthetic Chemical Company, which has a technical deal on with the Dow Chemical Company, and the Japan Oxygen Company are also conducting research in connection with commercial production of heavy water.

The Japan Mining and Mitsubishi Metal Mining Companies are studying uranium processing and prospecting for uranium resources in Japan. Both companies have already received subsidies from the government.

On the other hand, the Nissan Chemical Company is conducting research on the extraction of uranium from imported phosphate ore, which contains 0.01 to 0.15% natural uranium. Other firms carrying out research in connection with utilization of atomic energy are Mitsubishi Electric, Japan Carbon, and Tokai Electrode.



AUSTRALIA'S FIRST REACTOR, a 10-Mw D_2O research unit designed at Harwell, is part of the Australian Atomic Energy Commission's $12-million research program. It will be built on an 80-acre site within the AAEC's 160-acre area at Lucas Heights, Sutherland, near Sydney. Shown here are: one fuel element, one of the six control arms, aluminum D_2O container, graphite reflector, H_2O-cooled Pb thermal shield, steel tank lined with boral sheet, concrete biological shield, and various experimental facilities. Unit will be in a 70-ft-diam 70-ft-high steel building. It will be used for studies on fuel systems of molten U alloys or salts and for radiation damage tests. Data probably will be incorporated in package power reactors likely to be imported later from Britain. For more on the British and Australian programs, see pp. 12, 14

Industrial Applications

What does it cost to set yourself up for radioisotope work? Not much is the paraphrased answer given by V. P. Guinn, Shell Development Co., Emeryville, Calif., in a recent speech. "It is readily possible to equip a modest radiochemical laboratory with as little as $2,000," he said, "whereas an investment of $10,000 will equip one quite handsomely to undertake many problems of varying types." He noted that not only is the radiotracer method often the only way to solve a problem, it is often the easiest or least expensive way. (See NU, April '55, p. 18.) For example, using liquid scintillation counters, $10 worth of tritium (100 mc) can be diluted with 50,000 barrels of oil and still be detected with accuracy. The method is so fast that up to 100 samples can be prepared and counted per 8-hr day. Using crystal scintillators, $10 worth of cesium-134 (10 mc) can be accurately detected after dilution with 600,000 barrels of oil.

Surfacing steel extrusion die with radioisotope pinpoints wear. Wear studies by reactor-activating the entire wearing member and counting the radioactivity ground off are common (NU, June '55, p. 23; NU, Feb. '53, p. 46). But they suffer because there is no indication of just where the wear has occurred, size of wearing piece is limited by size of available reactor-irradiation facilities, and when testing tool steels, as in the case below, the induced radioactive tungsten has only a 1-day half-life. The method used by B. J. Jaoul, Ecolo National Supérieure des Mines, Paris, France, and reported at the June ASME meeting, eliminates these disadvantages.

The die is placed in a vessel and a plug is set in the center, leaving 0.05-cm annular space around the plug. Phosphorous-32, 1 mc in 2.5 ml of solution, fills the space. After 1-hr at 95° C the plug and solution are removed and the die lightly polished (0.1 micron) to remove the friable surface that formed. Calibration tests show that tracer has now penetrated to about 10 microns depth. Radioisotope absorption is not uniform, so an initial count is made along the die axis by averaging counts a number of times from four points 90-deg apart. Conical, 4-mm-thick lead shields placed over the G-M probe allow point-by-point counting. One shield has a 1-mm hole at its tip; subtracting the counting rate with a solid shield in place from the pierced-shield rate gives counting rate for each mm^2 of die surface.

After extruding *one* 33-ft-long stainless-steel tube—temperature is 1250° C—through the die, counting is repeated. Decrease in radioactivity shows wear location. Total amount of metal removal agrees with metal removal found by total-irradiation method. Since specific activity is 100 times higher, new method is faster and more precise.

Using the same tracer methods, autoradiographs map the wear in a simplification of technique. Simple comparison of autoradiographs shows how site of wear moves when the die is used repeatedly.

First tests of active-layer method used iron-55-iron-59 solution, but strong gamma rays required too thick a shield to allow the G-M probe inside the die for the point-by-point count.

ROUNDUP

News in Brief

Industry to study sewage treatment with radiation. Rudson Engineering Enterprises, Inc., San Diego, Calif., will evaluate the feasibility of recovering water and commercial fertilizer from sewage by treating it with gamma rays from waste fission products.

Encourages medical isotope training programs. Abbott Laboratories, N. Chicago, Ill., has made $2,000 available for grants-in-aid to educational institutions and hospitals which have courses in radioisotope usage.

AEC sets up civilian application division. Required by the law, this new division will be responsible for: regulations and licensing, pricing policy, materials distribution, information access, and nuclear export activities. Harold L. Price is director and Frank K. Pittman his deputy.

"Atoms for peace" fund receives grants. The Fund for Peaceful Atomic Development has received two new grants—$50,000 from the Rockefeller Brothers Fund and $5,000 from the Johnson Foundation. Walker L. Cisler, president of the Fund, says that "active contacts have been made or projects have been undertaken in a substantial number of countries, including India, Pakistan, Turkey, Egypt, Japan, Mexico, Canada, Belgium, France, Italy, Switzerland, Denmark and Germany."

AEC awards $400,000 for patent. Based on work done in '40 and '41, four scientists have received this sum from AEC for: "inventions and discoveries pertaining to the element plutonium and certain of its isotopes, in particular Pu-239 and its neutron fissionability as well as certain aspects of its chemical properties. Their work included the discovery that Pu in its lower oxidation state is carried from solution by certain precipitates, whereas in the higher oxidation states it is not." The men are: Glenn T. Seaborg, Joseph W. Kennedy, Arthur C. Wahl and Emilio Segre.

To award master's degree in nuclear engineering. A two-semester master's degree program will be offered this fall at Berkeley by the University of California's department of engineering. The program will include the university's radiation laboratory at Berkeley and Livermore. Particular attention will be focused on analysis, design, performance, prediction and cost of nuclear power systems.

U-233 is special nuclear material. After having announced in 1948 that U-233 is fissionable, AEC has now officially labeled the isotope to be "special nuclear material" so that it can be legally controlled under the new law.

National Research Corp. forms nuclear energy dept. This Cambridge, Mass., firm will offer engineering assistance in process design and engineering and business studies for companies considering entry into the atomic field. In addition, the company builds semicontinuous vacuum melting and casting furnaces, pumps and pumping systems, valves, gauges, gas analyzers and leak detectors.

Tracerlab plans meeting on radiation applications. Purpose of 3-day symposium in Boston, starting Oct. 19, is to acquaint the food industry with radioisotope uses in research, production, and process control. Details from Symposium Committee, Tracerlab, 130 High St., Boston 10, Mass.

Meeting on radioisotopes in testing. American Society for Testing Materials Committee E-10 will sponsor a Los Angeles meeting in Sept., 1956. Aim of the committee is to promote knowledge of radioisotopes in materials testing, and related fields, by advising other ASTM groups. Task groups are working on evaluations of needed specifications—materials that will be irradiated, detergency tests, tool and engine wear tests, backscatter gages, and other items. Prospective members—or speakers—should contact C. E. Weber, KAPL, General Electric Co., Schenectady 5, N. Y.

To try "streamlining" uranium mill operations. Vitro Uranium Corp., a division of Vitro Corp. of America, will put up a $100,000 pilot plant inside its Salt Lake City uranium mill. It is said that the extraction process to be used is "untried commercially in uranium milling." The pilot plant will be of sufficient size to permit plant scale test work.

General Dynamics Corp. expands nuclear work. The company will build a $10-million research lab devoted primarily to nuclear research and development with emphasis on reactor system design. Frederic de Hoffmann, who was recently named assistant vice president for nuclear planning of GD's Convair Division, was appointed vice president and general manager of the corporation's General Atomics Division.

N. Y. atomic exhibit Oct. 19—Nov. 3. Three groups —the Atomic Industrial Forum, the Fund for Peaceful Atomic Development and the Carnegie Endowment for International Peace—will put on this show at the Carnegie Endowment International Center. Information from Forum, 260 Madison Ave., N. Y. 16, N. Y.

81 more access permits granted by AEC. This brings to 148 the total number of organizations and individuals who have been granted L-clearances by AEC for access to confidential information on civilian uses of atomic energy technology. Many of the new permits are for organizations that have never been associated with atomic energy in any substantial way.

New graduate nuclear courses added. Oklahoma A & M, in a two-year program, will give two courses, "Introduction to Nuclear Engineering" and "Introduction to Nuclear Technology," in one year and then has arranged for students to work at Argonne National Laboratory for the second year with an MS in chemical engineering awarded on the basis of Argonne thesis work.

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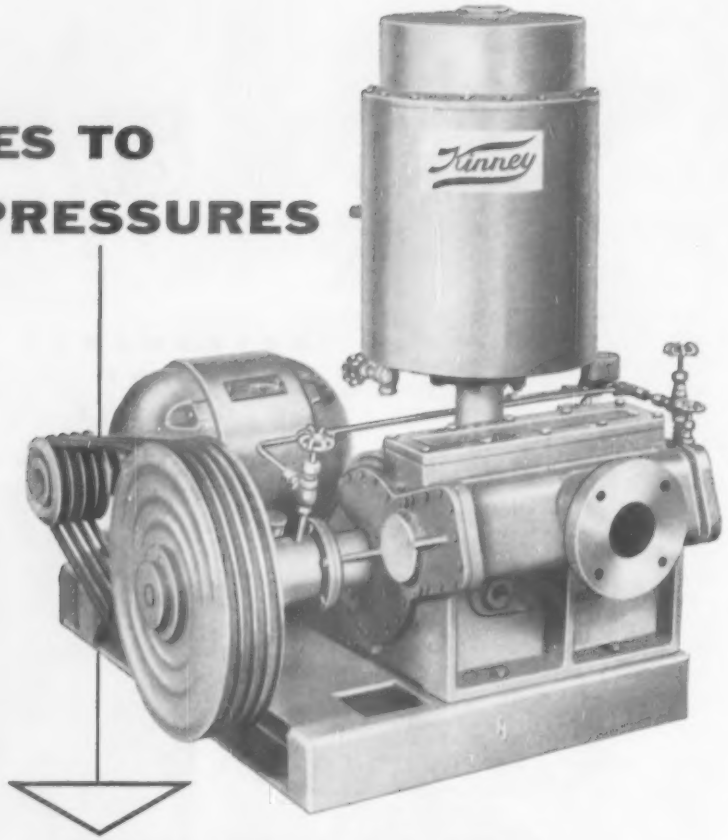

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NUCLEONICS AUGUST, 1955

Jerome D. Luntz, *Editor*

Hidden Target

A guest editorial by J. G. BECKERLEY, *former Director of Classification, U. S. Atomic Energy Commission.*

[EDITOR'S NOTE—*Controlling thermonuclear reactions for possible industrial power use has never been discussed publicly in this country by those concerned with the work, although AEC has had a priority program for at least three or four years. Even the existence of the project is never mentioned. Because there are some who feel that fusion reactors may one day be more important than fission reactors,* NUCLEONICS *invited Dr. Beckerley to discuss the effect on our national security of the policies being followed.*]

IT has been observed that many of the "quantum jumps" in technical progress are based on ideas conceived by relatively young men. Past experience also indicates that the subject-matter of an individual's ideas is determined by the knowledge he has inherited from predecessors as well as the nature of the contemporary technical scene.

Both these observations support the conclusion that the present AEC attitude on non-weapons thermonuclear energy, the development of fusion reactors, is unsound. By keeping all such work secret the probability of significant ideas being generated in the field is greatly reduced. The literature of the new generation of scientists and engineers is artificially devoid of basic papers on the subject. The stimuli of discussion in professional society meetings are absent. Those who are working in the field have lips sealed by AEC security regulations. Those who aren't working in the field either do not feel competent to discuss the subject or, because they are working on other classified projects, may believe that public discussion of a "verboten" subject will jeopardize their clearances.

As a consequence, the young physicist in graduate school does not even know what subjects to pursue most vigorously if he wishes to secure the basic knowledge necessary to work on fusion reactors. An aspirant to an engineering career faces the same variety of choices without guidance. Certain studies are essential to almost any advanced scientific and engineering work but others are determined by the individual's interest. It is a fact that the publication of most of the basic work on nuclear fission reactors has influenced university curricula and many students' academic careers. This influence was almost nil when nuclear reactor information was fully classified. The AEC's present silence will certainly hinder planning of university training in matters relevant to thermonuclear reactor development.

Not to be overlooked also is the major contribution of industrial research teams to idea generation. How can industry be expected to encourage its researchers to give attention to fusion reactor problems without knowledge of government-supported efforts? What about long-range planning in industry? Many companies are making commitments for sizeable expenditures on fission reactors. Shouldn't they be told of the prospects for fusionable materials supplanting fissionable fuels in electrical energy generation?

AT Geneva this month our 'idea' strength, as individuals and as a nation of industries, will be amply displayed. This strength is founded on published information beginning with the superficiality of the Sunday supplements, continuing in high school texts, museum exhibits, and on into thorough and scholarly work in university courses and technical societies.

Potential idea sources in the fission field are adequately cultivated. This is definitely not the situation in the fusion field. It is time for the AEC to discontinue the present short-sighted folly. It is time to publish, at the very least, sufficient data to assure an increasing supply of adequately trained young men with ideas. It is time to publish, at the very least, sufficient data to assure that industry is prepared to participate in a new technology if and when it develops.

The value of publication of information in increasing our national strength has been demonstrated for fission reactor development. Why should we doubt the benefits of publication of fusion reactor information?

Design and Operation for Direct-Maintenance Fuel Separation

Three-year performance record of direct-maintenance solvent-extraction plant for irradiated reactor fuels shows 11% time loss for maintenance, and only 60 mr/week exposure to maintenance men. Inherently low operating and capital costs, plus plant versatility, are additional advantages for this design

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THE METAL-RECOVERY PLANT is a radiochemical separations plant designed so that it could be built, operated, and maintained using standard industrial techniques. This article explains a typical process carried out, describes the building and equipment, summarizes the operating experience, and gives capital costs for the plant and for a similar scaled-up plant.

The plant is directly maintained (see p. 25), which is in contrast with procedure in other radiochemical-separations plants. Other plants are designed so they can be maintained without personnel contacting the equipment.

Built in 1951, the metal recovery plant serves as a small-scale production facility for recovering valuable materials and as a pilot-plant-type of research unit for studying chemical and engineering problems. It was designed for materials that could be separated most effectively by solvent extraction. Plant capacity is 750 lb of U/day.

Fuel Separation Process

Several types of reactor-irradiated fuels and valuable waste materials have been processed in the Metal-Recovery Plant. A typical feed is unenriched-uranium slugs from the Oak Ridge National Laboratory graphite reactor (*1*).

After the slugs are discharged from the reactor, they are stored under water for several months while short-half-lived fission-product activity decays. The decay curve is very steep during the first few months, and gross activity decreases by a factor of 10–100 (depending on irradiation history) during this time. Several fission products that could give trouble during solvent extraction decay to an insignificant amount. After several months the decay curve becomes relatively flat, and further decay storage is not economically feasible.

Process steps. The chemical process used for reactor-fuel separation may be divided into (*a*) feed preparation, (*b*) solvent extraction, (*c*) product treatment, and (*d*) waste handling.

Feed preparation consists of dissolving the slugs and adjusting the resulting solution to flowsheet specifications. Figure 1 shows the separation and purification p ocesses used. Uranium slug and aluminum jacket are dissolved simultaneously with nitric acid, using a catalyst. Dissolving is done continuously by adding slugs and acid and pumping off the resulting solution at a constant rate and at desired concentration. Processing is continuous.

After feed is prepared solvent extraction is used to separate the uranium, plutonium and fission products. Primary chemical variables in solvent extraction are salting strength, acidity, and valence state. By proper manipulation of these variables, the separation is effected.

Aqueous feed, containing U, Pu, and fission products, is pumped to the middle of the first extraction column. Pu and U are extracted into the organic solvent—tributyl phosphate dissolved in a kerosene-type hydrocarbon. Nitric-acid scrub from the top removes some of the 0.1% fission products that extract into the organic phase. The organic phase overflows to the partitioning column where Pu is reduced and conse ,uently its distribution coefficient is highly in favor of aqueous solutions. The Pu back-extracts into the water stream and leaves the bottom of the column.

A small organic stream fed in the bottom prevents any U from leaving the column with the Pu. Organic phase, containing U, cascades to the bottom of the stripping column. Here water strips U into aqueous solution that leaves the bottom. Solvent goes to a recovery column for a water wash that removes remaining fission products. Solvent is recycled continuously back to the first two columns.

From solvent extraction we get three streams: (*a*) highly radioactive solution

* Operated by Carbide and Carbon Chemicals Co. for the U. S. Atomic Energy Commission.

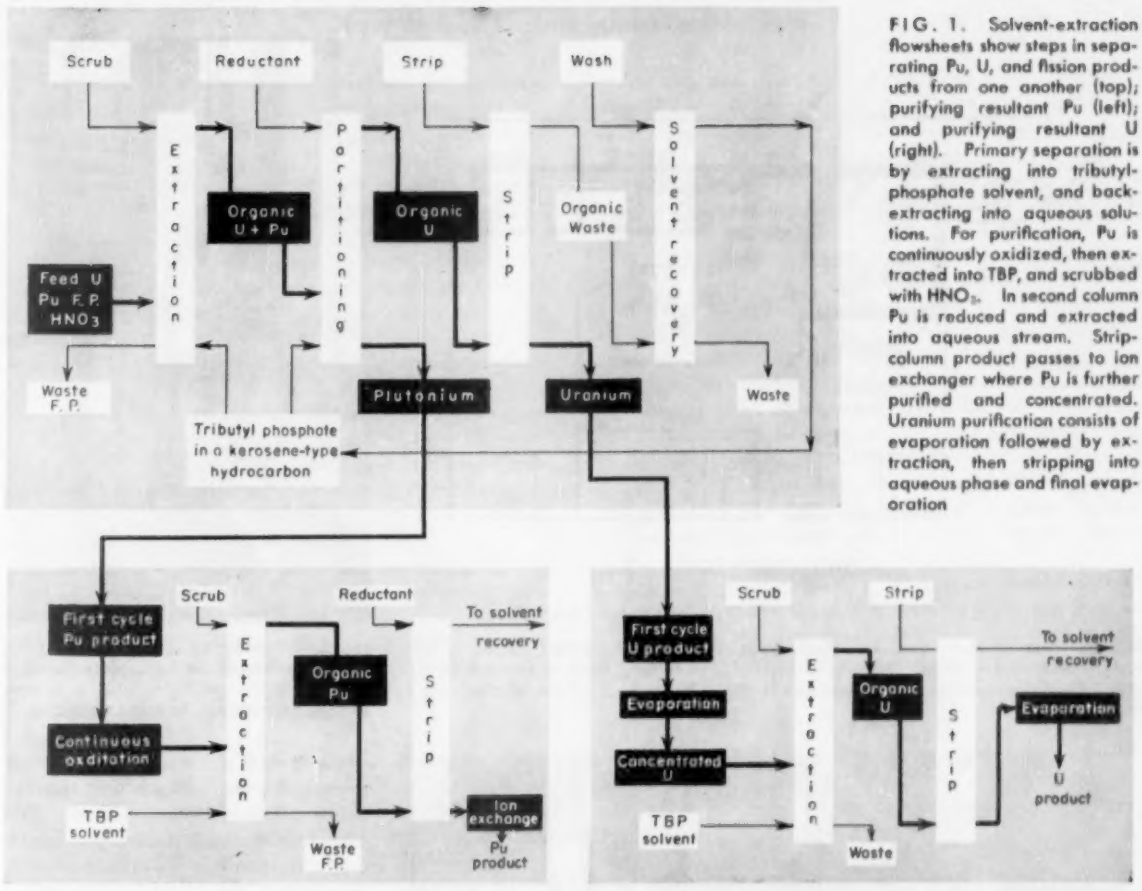

FIG. 1. Solvent-extraction flowsheets show steps in separating Pu, U, and fission products from one another (top); purifying resultant Pu (left); and purifying resultant U (right). Primary separation is by extracting into tributyl-phosphate solvent, and back-extracting into aqueous solutions. For purification, Pu is continuously oxidized, then extracted into TBP, and scrubbed with HNO_3. In second column Pu is reduced and extracted into aqueous stream. Strip-column product passes to ion exchanger where Pu is further purified and concentrated. Uranium purification consists of evaporation followed by extraction, then stripping into aqueous phase and final evaporation

containing the bulk of the fission products, (*b*) aqueous solution of U, and (*c*) aqueous solution of Pu. Pu and U are further purified by an extraction and stripping cycle, and by ion exchange (see Fig. 1 for details). Then they are packed as concentrated solutions for shipment to other sites.

Plutonium and uranium are separated from fission products by a factor of 10^5–10^6; Pu in U product is <10 parts per billion; U in Pu product is $<1\%$. Yields of Pu and U are $>99.5\%$ (*2*).

Waste streams are concentrated for storage. Each ton of U processed results in 400 gal of radioactive waste that must be stored.

Nitric acid is evaporated from the extraction-column raffinate, and then concentrated for re-use by fractionation.

How the Plant Is Built

Except for the shielding the plant looks very much like other chemical plants. Specifications for valves, instruments, filters, heat-transfer equipment, jets, and pumps were written so that all could be procured off-the-shelf from commercial vendors. All materials of construction are common to the chemical industry. Tanks, columns, and other equipment were designed fabricated and installed using common industrial techniques. The equipment is connected with pipe or tubing. Closures are made with standard flanges, tube fittings, and welds.

Figure 2 shows a floor plan of the structure. A hoist and monorail lower shipping containers of radioactive feed into a water-filled canal. Fuel elements are removed under about 10 ft of water that acts as a γ-shield.

Feed material is loaded into a dissolver tank from the canal. The 500-gal dissolver is in a concrete-walled underground pit between the canal and the first cell. Feed is dissolved in HNO_3 and then transferred to the feed-preparation cell that contains three 2,000-gal tanks and a centrifuge.

From the feed-storage tank the solution is pumped to the solvent-extraction equipment located in six small cells. The first of these has the first column and the waste evaporator. The next has two columns, an evaporator, storage tanks and heat exchangers. Final purification and packaging equipment is in the last cell. Intermediate cells contain columns, storage tanks, and solvent-treatment facilities. Average volume of the small-cell tanks is 300 gal. Figures 3 and 4 show two plant cells.

Electrical and air switches for operating the pumps, valves, and other mechanical devices are located in the control room. An instrument console in this room has indicating and recording instruments to follow the process, and automatic-control devices for remote operation.

All steam, water, and air is supplied to the processing equipment by lines that enter the cells from nonradioactive areas where their controls are located,

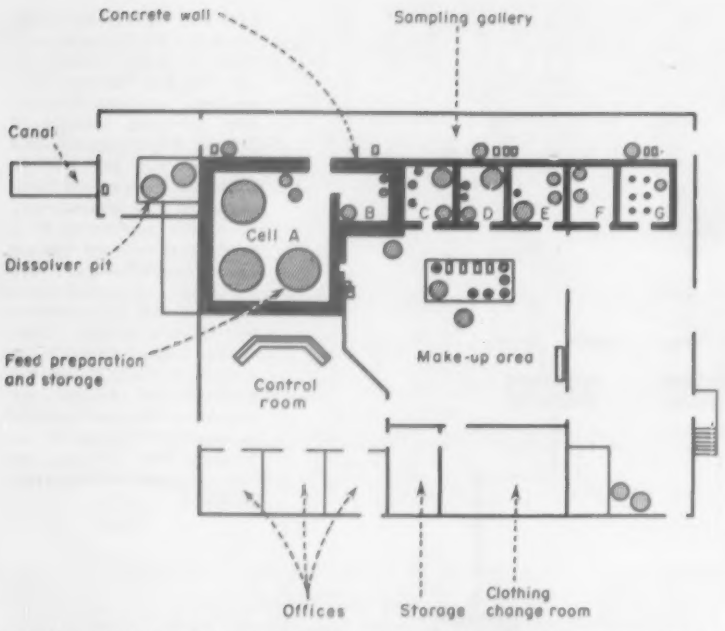

FIG. 2. Plan of Metal-Recovery Plant shows division of equipment according to activity level and function. Building is one story, 94-ft long, 68-ft wide, and 24-ft high. Feed preparation and storage cell is 21 × 18 ft, each of the smaller cells is about 8 × 8 ft

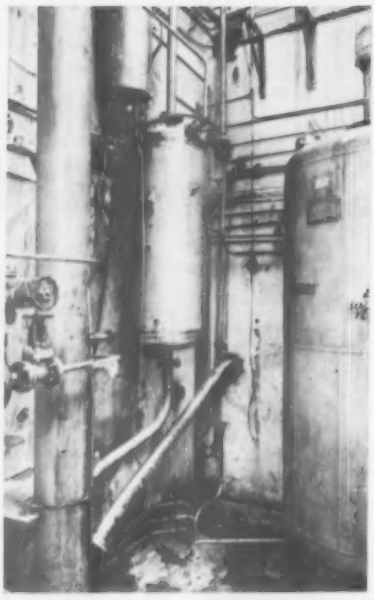

FIG. 3. View inside E cell shows strip column for U purification (at left). Pulse wave is transmitted through 3½-in. pipe to column. Used-solvent storage tank is at right

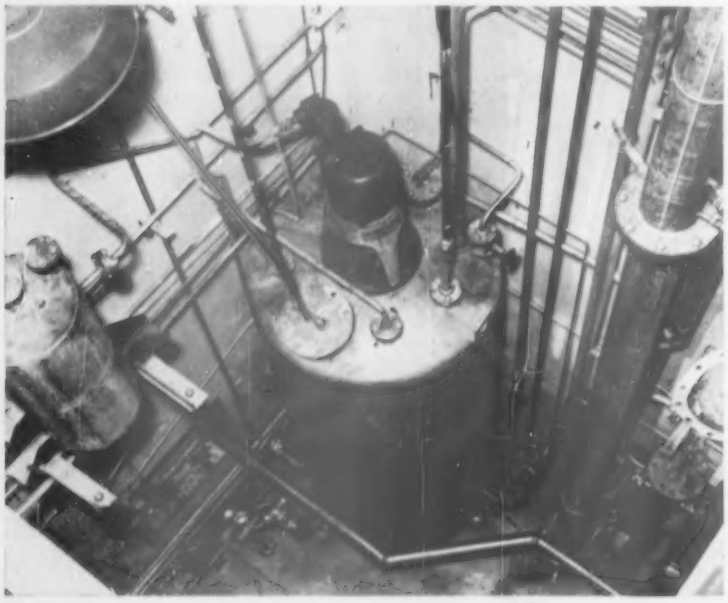

FIG. 4. View inside D cell shows solvent wash column (right), storage tank for recovered HNO_3 (center) and phase separator (on left wall). Bottom of column extends beneath floor into stainless-steel-lined hole

while in the solution-make-up room are tanks, pumps, and other equipment for preparing nonradioactive solutions. About 14 streams are pumped continuously to the cell equipment.

Next to the cell wall is the sampling gallery where several small lead-shielded devices sample the process solutions.

Shielding. Required shielding is provided by 2-ft concrete walls around the first two cells and 8-in. concrete walls around the other cells. Certain pieces of equipment are unit shielded with lead sheets when required. This shielding augments the concrete shielding and permits work on one piece of equipment in a cell without having to completely decontaminate all equipment in the cell. Personnel-exposure experience with this plant is found in the section "How Direct Maintenance is Possible" on the next page.

Processing Equipment

All equipment is made of stainless steel, types 347, 309Scb, and 304. Gaskets are of Teflon. Blue-African asbestos is used on some large flanges.

Pulse columns. Solvent-extraction contactors are pulsed columns 20–40-ft high and 2.5–10-in. diameter. Columns are packed with 2-in. spaced horizontal stainless-steel plates with ⅛-in. holes to give a 23% free area. Reciprocating pistons located outside the cell area pulse the column's counter-flowing liquids. Column pulse amplitude and frequency are about 1 in. and 60 cycles/min.

Pumps. Radioactive feed is pumped from dissolver to feed-adjustment tanks, and from these tanks to the primary-cycle extraction columns by Pulsafeeder pumps. Pump check valves and displacement heads are

How Direct Maintenance Is Possible

The Metal-Recovery Plant was designed as a direct-maintenance facility. Equipment and processing cells can be decontaminated to permit normal direct maintenance.

Arrangement of equipment. *To facilitate maintenance the process equipment is segregated according to function and activity level. For instance, the dissolver, being the greatest source of radiation, is located in a cubicle by itself. Feed preparation and storage equipment is in a cell by itself. Subsequent cells isolated from each other contain a portion of the process equipment. In this manner, only a portion of the equipment need be decontaminated for maintenance.*

Construction materials. *To simplify decontamination all equipment and piping is of stainless steel to provide resistance to the decontaminating agents, even though process solutions may not require stainless. Equipment supports are of stainless steel. Floors in the process cells are lined with stainless steel, and the walls are coated with corrosion-resistant organic coating. Porous insulating materials that absorb and retain activity are not used in the cells.*

Decontamination procedure. *When necessary for emergency repair, equipment is decontaminated by flushing with mildly corrosive mineral acids and caustic solutions. Decontaminant usually is in contact with the equipment for a few hours, at room temperature. These treatments are repeated until activity is low enough to allow craftsmen to work directly on the equipment. On the average, six to eight cycles of this type are needed for most items. Individual equipment items can be sufficiently decontaminated in ½–3 days to allow emergency maintenance. The needed time depends on activity level and plant location. Complete decontamination of all equipment takes about 2 weeks, using the normal staff.*

Radiation-exposure experience. *It is estimated that average exposure for cell equipment changes and repairs has been about 60 mr/week. This is 20% of the permissible exposure for operating and maintenance personnel. The exposure is less than that received in sampling and other operations not connected with hot-cell maintenance.*

Time-operated efficiency. *During the past three years five separate production programs have been completed in this plant. Each program used a different feed and chemical flowsheet, and extensive equipment changes were required. Since the plant first went into operation it has been shut down for five months for these equipment changes. Only one month of this was for decontaminating equipment.*

Loss of production because of decontamination and cell maintenance was 10% in 1952, 14% in 1953, and 10% in 1954. These are very reasonable values, and compare well with down time in remotely maintained separations plants.

located inside the cells. Drive mechanisms are in the operating area. Other radioactive streams are transferred by canned-rotor pumps and steam jets.

Evaporators and fractionating column. Most of the evaporators are continuously operated, long-tube, natural circulation, tube-and-shell evaporators. Nitric acid leaving the extraction-column waste evaporator passes to a fractionator. The fractionator is 25-ft high, 24-in. diameter, and has bubble-cap trays spaced 12 in. apart. Acid recovered is 12*M*. Overhead is 0.01*M*.

Instruments. In number and in type instrumentation is about the same as in the average modern chemical plant. Pneumatic instruments with differential-pressure transmitters are the most common. Temperature is measured with standard thermocouple and resistance-type sensing elements. No radiation instruments are used except for monitoring nonradiochemical areas, and during maintenance. Differential pressure is measured at 80 points and temperature is measured at 24 points.

Valves. Valves are used whenever convenient for control or on-off service. About 20 valves are in the radioactive areas. Most of these are air operated. Other valves are operated from the inactive areas by extension handles. Bellows-sealed valves are usually used in the highly radioactive areas.

Ventilation. The plant has three separate ventilation systems for the dissolver, the cell vessels, and the cell atmosphere. Pressure on the process vessels is negative with respect to the cell atmosphere. The three air streams are discharged to the bottom of a tall stack, and after dilution with a large amount of air are discharged to the atmosphere.

Capital Cost of Plant

Capital cost of this facility was about $800,000. This includes only the building and equipment just described. Other ORNL facilities are used for waste storage, analytical laboratory, and other services.

It is estimated that a plant with a capacity of 30 tons of highly irradiated uranium per month could be constructed at a new site for $6,000,000, including costs of the necessary analytical laboratory, waste storage for one year, off-gas-handling equipment, and other required service facilities. Ohlgren (3) estimates that a remotely operated plant for both separating U and Pu and reconverting them to metallic state would cost $6-million and handle 12.5 tons/month.

Operating staff. The ORNL Metal-Recovery Plant is staffed with 21 people, exclusive of analytical, maintenance, and service personnel. Overall supervision and planning requires three technical men. Actual operation is done by one foreman and three operators assigned to each of four rotating shifts. In addition, eight technicians are required in the analytical laboratory. They do 60 analyses on the 30 control samples submitted each day.

In Summary

Performance of the Metal-Recovery Plant has demonstrated that low-cost radiochemical plants can be operated with high on-stream efficiencies, and can be directly maintained with low radiation exposure of operating and maintenance personnel. Such plants are particularly well suited for processing diverse irradiated materials that cannot be economically processed in large plants.

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This article is based on a paper presented at the American Nuclear Society meeting, University Park, Pa., June 29, 1955.

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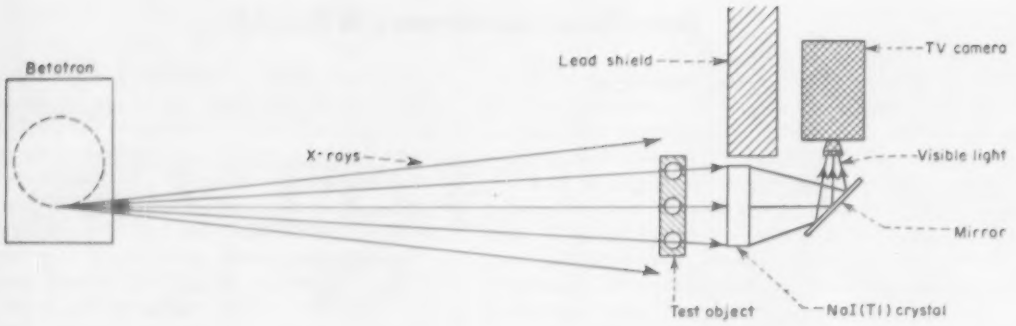

Scintillation Crystal-TV Device X-Rays Objects in Motion

Here's how this new instrument works: 50-Mev X-rays pass through specimen and form visible image in 1-in.-thick 7⅛-in.-diameter NaI(Tl) crystal. Image is reflected into TV pickup tube and displayed on monitor screen. Resolution is good; contrast is somewhat inferior to film. The technique is a very promising one

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THE INSTRUMENT described in this article continuously displays pictures produced by 50-Mev X-rays.* This is accomplished with a NaI scintillation-crystal image converter, which transforms the X-ray image into an optical image, and a television camera, which views the converter and reproduces the image on a remote monitor.

An instrument of this general type has been used by Morgan since 1951, for fluoroscopy with 70-kev X-rays (*1*). His instrument uses a fluorescent screen as an image converter. If the X-ray energy is increased one thousand times, to 50 Mev, the conversion efficiency of such a screen drops drastically. This sharply limits the value of his instrument in those applications demanding highly penetrating X-rays.

In the instrument discussed in this report, efficient conversion of high-energy X-ray images has been attained by using a thick scintillating NaI(Tl) crystal as a converter. Tests have shown that the sensitivity and defini-

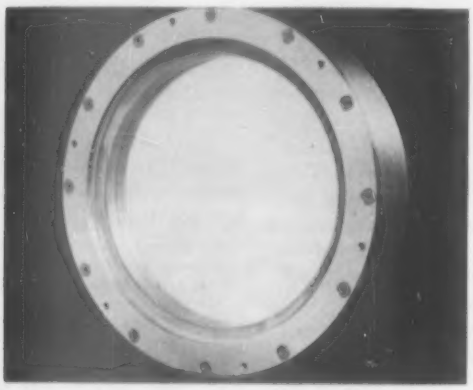

FIG. 2. Scintillation crystal used to convert X-ray image to light image. Dimensions are 7⅛ in. diameter × 1 in. thick

* The X-ray energies quoted in this article always refer to the peak energy of a bremsstrahlung spectrum.

FIG. 1. Setup for fluoroscopy with scintillation crystal and television camera

tion of such an instrument are good enough to give it some practical value.

Description of Apparatus

The complete instrument is shown in Fig. 1. X-rays from the NBS betatron emerge through a hole in the lead wall shown at the upper right. These bombard the test object, in this case a small compressor belt-driven at ~8 rpm.

Those X-rays that penetrate the compressor enter the crystal converter and form a visible radiographic image. Some of the light produced in the crystal travels in the same direction as the incident X-ray beam, and is reflected by a 45-deg mirror into the television-camera lens. An intensified replica of its image, showing internal motion, is displayed on a TV receiver.

An oblique view of the crystal is shown in Fig. 2. X-rays enter the back face, through a thin aluminum wall. They pass through a front-surface glass mirror, which is used to double the sensitivity of the converter, and then enter the crystal itself. This is a 1-in.-thick, 7⅛-in.-diameter NaI(Tl) crystal, grown and potted by Harshaw Chemical Company, Cleveland, Ohio. Light produced in the crystal emerges through a glass window in contact with its front face.

The 45-deg mirror separates the useful light from the X-rays that penetrate the crystal and which might damage the lens and camera tube. The lens is a 110-mm $f/0.75$ Kodak Fluro Ektar, used at magnification ⅛. The camera is one unit of a 525-line Du Mont TA-124-E closed television chain. It uses an RCA 5820 image-orthicon tube.

In use, crystal, mirror, and lens are enclosed in a plywood box, blackened on the inside to absorb light produced in the crystal that does not travel toward the lens. The image end of the lens juts out of the box and is normally bolted to the television camera. For direct investigation of the crystal image, the television camera can be replaced by a photographic plate holder.

Crystal Performance

Image definition. First tests of crystal image definition were conducted by photographing high-contrast images produced by placing lead objects in the X-ray beam. These early photographs showed no significant variation in image definition as X-ray energy was varied between 20 and 180 Mev. They also qualitatively confirmed the hypothesis that the image definition near the crystal center was better than that near the periphery when no correcting lens was used. (See p. 29.)

The instrument has since been used to look through steel mechanisms such as the compressor of Fig. 1. A photograph of the crystal image produced by 45-Mev X-rays penetrating this object is shown in Fig. 3. It was taken with a plate camera using a Kodak SA1 spectroscopic plate. The major components, piston, connecting rod, cylinder wall, crankshaft counterweights, and crankcase, can all be distinguished, although finer detail is lacking.

Image contrast. A test has been made of the minimum X-ray image contrast that can be seen by ¼-, ½-, and 1-in.-thick crystals through several inches of steel, using 22-Mev X-rays. The images studied were produced with 2% steel penetrameters, and were recorded on Kodak SA1 plates.

The test results appear in Table 1, where the entries are the smallest penetrameter thicknesses that can be seen through t inches of steel, expressed

Applications

The instrument presented here is potentially a useful tool for both industrial quality control and research. It could be used, for instance, to inspect large castings for flaws, a job that is commonly done with X-ray film. Although in its present state of development it produces an image whose quality is inferior to that which can be attained with film, further development work should at least partially remedy this.

The abilities of the instrument are not fully exploited unless it is used to study motion in the test object. In its present state, the instrument can successfully display internal motion which is slow enough to be followed by eye. More rapid motion must be slowed down artificially. If the motion is cyclic, this could be done quite simply by stroboscopic techniques, gating the X-ray machine to produce a burst of X-rays only when the motion is in the proper phase. This could be used either to stop the motion completely, or, by slowly changing the phase of the gate, to reduce the speed of the motion so that it can be observed directly.

Crystal Image Definition

Figure 5 shows a cross section of the scintillation crystal, bombarded by X-rays from a point source and viewed by a small-aperture optical imaging device, such as a pinhole camera. If the crystal were an ideal image converter, light produced by all the X-rays traveling along a given line, such as A or B, would be imaged as a point by the viewing camera. A rough analysis of the manner in which the crystal may be expected to deviate from this ideal follows.

Blurring caused by image conversion. *Beam A includes all X-rays traveling along the source-camera axis. Some of these X-rays will interact with the crystal, producing secondary electrons and X-rays. These secondary products will in turn produce ionization and excitation within the crystal, and a fraction of this excitation will reappear as isotropically radiated visible light. If the ionization were limited to the irradiated portion of the crystal, X-ray beam A would produce a line of isotropic light sources in the crystal, as shown by the heavy line in Fig. 5. The pinhole camera would image this line as a point, satisfying the criterion for an ideal converter.*

Actually, it is well known that ionization within a thick absorber spreads out radially from the beam shadow (2). The ionization density is a complicated function of depth in the absorber and radial distance from the beam axis. Consequently, rather than a sharp line, the camera sees a more diffuse source of light, as indicated by cross hatching in Fig. 5. Obviously, the smaller the effective diameter of this source, the better the image definition and the more closely does the crystal approach an ideal converter.

Early tests of image definition, conducted with 90-Mev X-rays, set an upper limit on the blurring introduced during image conversion. Camera-image blurring was no larger than 0.015 in., when camera magnification was 1:1.

Blurring caused by crystal depth. *Returning to Fig. 5, consider X-rays that travel along line B. If the blurring discussed in the previous section is ignored, these X-rays produce an oblique line source of light in the crystal. The crystal mirror produces an image of this source as shown by dotted line number 1. These two lines, the source and its image, form a V, which subtends an angle δ at the camera aperture. The magnitude of δ is a good measure of the image blurring introduced by finite crystal depth.*

But δ may be reduced by placing a properly ground lens in contact with the crystal, as indicated. This lens minimizes δ when it is ground so that it will focus parallel light onto the camera aperture. Then the V-shaped source will effectively be rotated as shown by dotted line number 2. Such a lens has been ground for this instrument, but has not yet been mounted or tested.*

One can reduce δ further by replacing the mirror with a black surface to absorb light. Although this halves the instrument sensitivity, it eliminates one leg of the V, so that with the proper lens, the camera can see the source line end on. δ will still have a finite size at some portions of the crystal face, however, because of the spherical aberration of a simply ground lens.

* This is an approximation, valid only if the ratio of crystal radius to crystal-aperture distance is small. For the instrument of Fig. 1, this ratio is about 1/10.

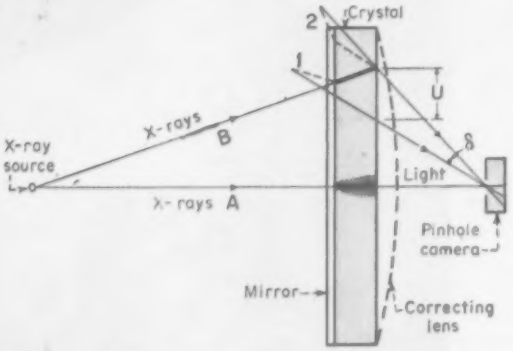

FIG. 5. Optics of image formation in scintillation crystal

The values of δ_{max} shown in the following table were calculated for the instrument shown in Fig. 1, using a source–crystal distance of 4 meters, a typical value, and a crystal–aperture distance of 88 cm. They indicate the improvement in definition resulting from the addition of a lens and the removal of the crystal mirror. The table also lists the maximum image unsharpness, U_{max}, as defined in Fig. 5.

Situation	δ_{max} *(min of arc)*	U_{max} *(in.)*
No lens	11.1	0.112
Lens added	1.3	0.013
Mirror removed	0.1	0.001

Blurring caused by increasing lens speed. *Since camera-image illumination varies as the inverse square of the lens f-number, considerable gain in sensitivity results by replacing the pinhole with a fast lens. The effect of this on image definition will now be discussed.*

The line source of light produced by X-ray beam A in Fig. 5 generates a camera image spot whose outside diameter varies inversely with the viewing-lens f-number (3). The distribution of light within that image spot is the subject of a detailed investigation now under way in this laboratory. Preliminary results indicate that when a line source of light is transparent to its own radiations, as is the case here, the half-intensity diameter of the image spot is a very insensitive function of lens speed, and is never much larger than the diameter of the source line. These results justify the use of the fastest lens available.

Also, with a large-aperture lens, diffraction, tacitly ignored until now, has a minor effect on image definition. For example, the Kodak f/0.75 lens produces a diffraction pattern of a point source of light with a half-intensity width that subtends an angle of only 0.8 sec of arc at the lens aperture. This angle is an order of magnitude smaller than even the smallest value of δ_{max} listed above.

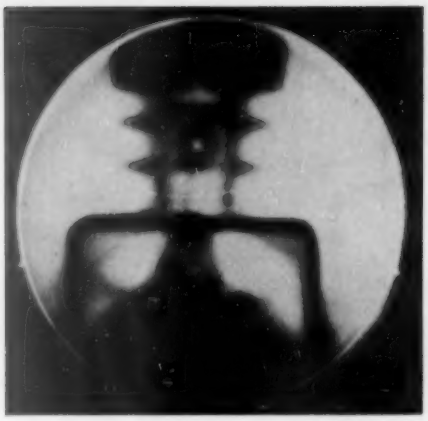

FIG. 3. Crystal image of small compressor in Fig. 1. An air bubble in the silicone fluid is outlined around cylinder head. It has since been removed

FIG. 4. Betatron used at National Bureau of Standards to generate high-energy X-Rays for scintillation-crystal fluoroscopy

as percentage of t. Each number is the average of the judgment of two plate readers, the criterion being that a penetrameter could be "seen" if its outline and the outline of at least one hole could be distinguished. Table 1 also shows the minimum contrast that can be seen if the crystal is replaced by an Eastman X-ray film (*4*).

These numbers show that there is little difference between the three crystals, although the thinner ones appear to be somewhat better. None of them is as sensitive as X-ray film, which can reproduce images with only about ½ or ⅓ of the minimum crystal contrast.

Image brightness. The amount of light produced in the 1-in.-thick crystal by an X-ray beam of unit intensity was measured as a function of X-ray energy. At each energy, the light was measured with an RCA 5819 photomultiplier that viewed a 1-in.-square section of the crystal, and the X-ray beam intensity was measured with a transmission monitor, which was calibrated in ergs/cm²/sec by means of a secondary standard consisting of a Victoreen r-thimble encased in a ⅛-in.-thick lead shell.*

The results shown in Table 2 have been normalized to unity at 20 Mev. Each number is the result of several photomultiplier measurements and several monitor calibrations. Calculated rms deviations are also shown. According to these figures, instrument response does not vary appreciably between 20 and 80 Mev.

The crystal brightness has not been measured in absolute terms. However, the absolute sensitivity of the assembled instrument has been measured. Using 20-Mev X-rays, some high-contrast image structure could still be seen on the television monitor screen when the X-ray intensity at the crystal was reduced to 5 erg/cm²/sec. According to Table 2 the same should be true for all energies between 20 and 80 Mev.

* For the X-ray energies used 1 r/min measured with the r-thimble corresponds to ~50-erg/cm²/sec beam intensity (*5*).

Crystal Discoloration

The equipment shown in Fig. 1 was assembled as an exhibit during February of this year. Using 45-Mev X-rays from the NBS betatron (Fig. 4), a TV picture of the moving parts inside of the compressor was displayed on a 21-in. monitor screen. During this demonstration period, the crystal was bombarded for a total of 24 hr at an average rate of about 1,250 erg/cm²/sec, giving a gross exposure of about 10^8 erg/cm². This is equivalent to 36,000 r measured with a Victoreen thimble in a ⅛-in. lead shell.

When the crystal was examined after this exposure, discoloration was found. Although parts of the crystal that had been protected from the X-rays by the compressor steel were still transparent, those parts exposed to the direct beam had turned brown. Subsequent experiments with a small crystal showed definitely that it was the crystal, rather than the glass window or the silicone fluid, that had discolored.

After exposure to sunlight for several hours, most of the crystal discoloration disappeared. As would be expected, the rate of bleaching decreased drastically with time (*6*), so that one month later minute traces of the compressor image could still be seen. However, after the first few minutes of bleaching, the image was too faint to interfere with normal use of the instrument.

* * *

I would like to express my gratitude for the constant help and guidance of Dr. H. W. Koch, who originally suggested this project. Work on the project was sponsored by the U. S. Atomic Energy Commission.

TABLE 1—Percent Thickness Change Resolvable

	Steel thickness, t (in.)				
Detector	*2*	*4*	*6*	*8*	*10*
¼-in. crystal	6.0	2.5	2.7	2.0	—
½-in. crystal	4.5	3.0	2.7	2.3	2.6
1-in. crystal	5.5	4.0	3.0	3.0	—
Eastman X-ray film*	2.0	1.5	1.3	1.3	1.2

* The 2, 4, and 6-in. sensitivities were measured with Type M film, and the 8 and 10-in points with Type A film.

TABLE 2—Crystal Sensitivity

Energy (Mev)	*Sensitivity* $\left(\frac{\text{light photons}}{\text{erg/cm}^2\text{/sec}}\right)$
20	1.00 ± 0.08
40	0.86 ± 0.05
60	0.84 ± 0.05
80	0.85 ± 0.05

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Using Boron-Trifluoride Gas for Reactor Control

Fine adjustment of reactivity can be accomplished by varying pressure and thus the number of boron-10 atoms in a gas container in the reactor core. But boron burn-out and irradiation-induced changes in molar composition of the gas make long-term pressure calibration difficult, so boron content must be monitored

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A SIMPLE REACTOR CONTROL system using boron-trifluoride gas as the neutron absorber has been installed on the Hanford-305 test reactor. A similar control system could be applied to other research reactors such as the Materials Testing Reactor. Both the present system and possible applications are discussed in this article.

The principle of this type reactor control is quite simple. If BF_3 gas is introduced into a tube located in the neutron flux, some of the neutrons will be absorbed by the B^{10} isotope in the gas. The number of neutrons absorbed will be a function of the number of B^{10} atoms present in the flux. Since this is proportional to the pressure exerted on the gas, the macroscopic absorption cross section of the gas in the control can be changed by varying the pressure.

A gaseous control system would be much less expensive than a system using control rods. Also, very fine reactivity control can be obtained if the system is carefully designed.

The danger of gas leakage during reactor operation can be minimized by periodically pressure testing the control system when the reactor is not operating. But the possibility of pressure loss is always present. Therefore, a fast-acting dependable safety system is required if this type control is used on a reactor that operates at a significant power if the reactor is not inherently fail-safe. If reactor characteristics are such that failure of the normal control system would be disastrous, the gas-type control system would not appear to be applicable for use as the primary control system.

305-Reactor BF_3 Control

The Hanford 305 test reactor was considered ideal for application of a BF_3 control system. This reactor operates at very low power and has negative metal and graphite temperature coefficients of reactivity.

A general description of the 305 reactor and its use is given with Fig. 1.

Figure 2 shows schematically the control-system components. The control tube was made from a $\frac{3}{8}$-in.-diameter aluminum tube. The small tube connecting the control tube to the bellows is also made of aluminum. After the system volume, the desired pressure range and the travel of the linear actuator were determined, it was a simple matter to calculate the size of the bellows required.

The reactivity effect of the BF_3 control system was determined in much the same manner as that of test specimens (see p. 31), except that the effect was determined at various pressures so that a calibration curve could be made. It was found that over the narrow pressure range used in this application, the calibration curve was essentially linear. Later recalibrations indicated that no measurable change in control strength of the BF_3 gas had occurred.

A continuous burn-out of the B^{10} isotope occurs while the reactor is operating. At the low flux density used in this reactor, it was calculated that the change in control strength thus caused would be negligible. However, if this type control were to be used in research reactors having a much higher flux, such as the MTR or the Brookhaven reactor, the problem of B^{10} isotope depletion would become a significant factor.

Boron Burn-Out

The rate at which an element is transmuted by irradiation is described by the differential equation

$$dn/dt = -N\phi\sigma_a$$

Integrating

$$\int_0^t dn/N = \int_0^t \phi\,\sigma_a\,dt$$

$$\ln N\Big|_0^t = -\phi\,\sigma_a \int_0^t dt = -\phi\,\sigma_a\,(t - t_0)$$

At $t = 0$, $N = N_0$

$$\ln N - \ln N_0 = \ln (N/N_0) = -\sigma_a\,\phi t$$

Therefore, $e^{\ln(N/N_0)} = e^{-\phi\sigma_a t}$, where σ_a is the absorption cross section in

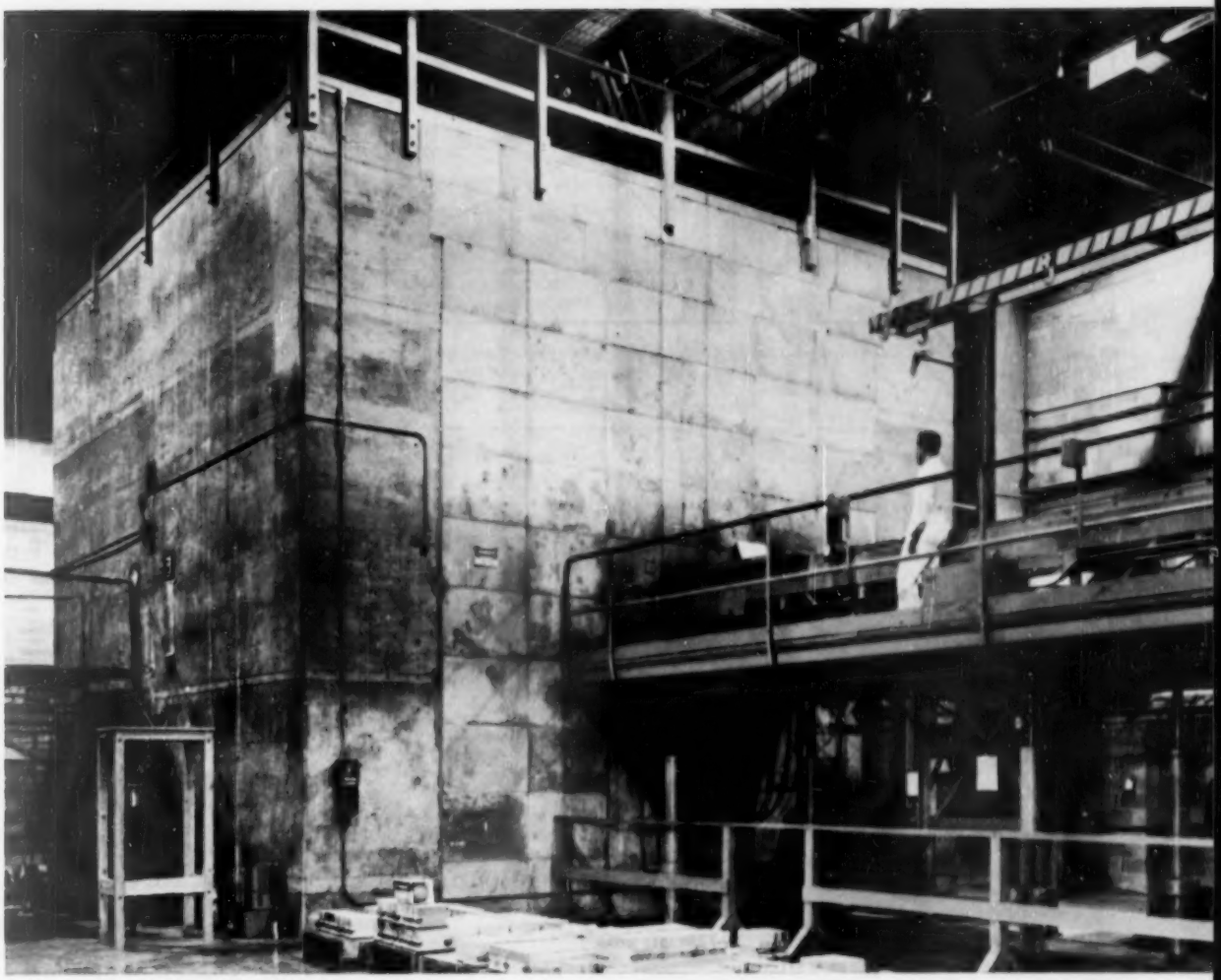

FIG. 1. Hanford 305 test reactor is uncooled and graphite moderated; it is fueled with natural uranium. Normal power level is 6 watts. Graphite train on elevated platform in foreground holds test specimens; height is adjusted by six power-driven screws to charge train and test pieces in any of available test holes. Control and shim rods enter reactor from far side. Vertical safety rod is also provided. Any one rod can shut reactor down. The reactor weighs 1,000 tons

How Hanford 305 Test Reactor Is Used

This reactor is used to determine the amount of reactivity absorbed by a given amount of material. For routine tests, a graphite train containing material of known nuclear purity is charged into reactor core. Shim rod is withdrawn to a position such that, after the vertical safety rod is withdrawn, the control rod will be withdrawn roughly 100 inches before the reactor goes critical. Control and shim-rod positions are then recorded to the nearest 1/1,000 in.

Barometric pressure is also recorded. This reactor is not sealed from the atmosphere, and variations in ambient pressure have a relatively large effect on available reactivity. Corrections are therefore made to compensate for any change.

After the graphite train bearing the material of known purity is removed from the reactor core, the material to be tested is placed on a similar train and charged into the reactor. Control and shim rods are again positioned carefully. Any difference in final position is noted.

By means of a rod calibration curve, the difference in reactivity absorbed by known and unknown samples can be determined. Reactivity determinations can be made with an accuracy of ±0.002 inhours. Method detects 0.1 ppm impurities. Built in 1944, the reactor is the world's third.

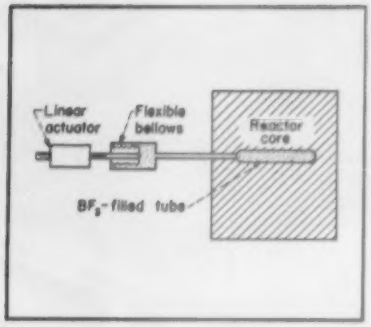

FIG. 2. BF_3 control system designed for use on 305 test reactor

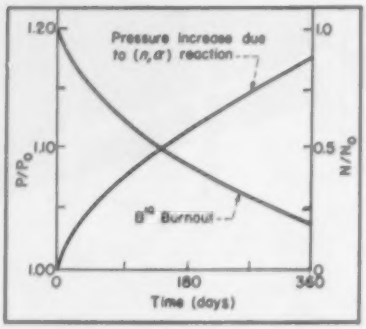

FIG. 3. Boron-10 depletion and gas-pressure increase as a function of time

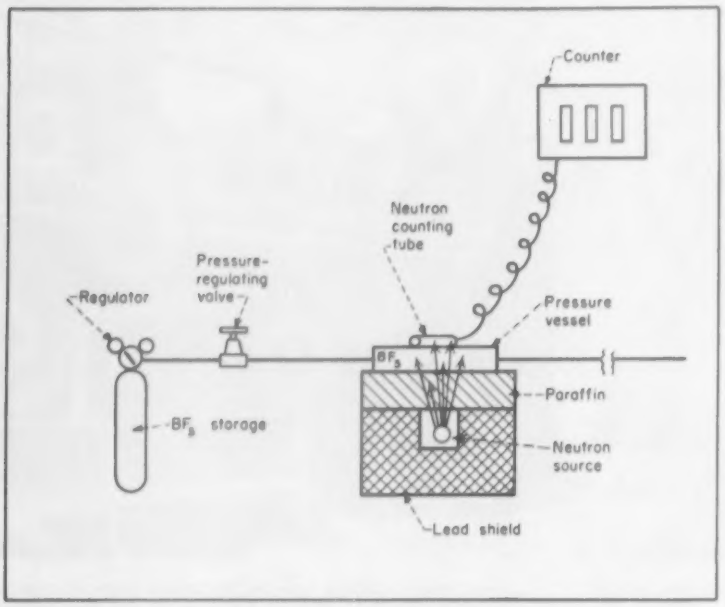

FIG. 4. Boron-10 isotope monitor provides measurements directly proportional to control strength

barns, ϕ is flux density in n/cm²/sec, N_0 is number of atoms present at time $t = 0$, and N is number of atoms of an element present at any time after $t = 0$.

Using this relation, it is a simple matter to determine the rate at which the B^{10} isotope would be depleted if a sealed tube containing BF_3 were placed inside, say, the MTR reactor tank. The average flux at this position is 2×10^{13} n/cm²/sec. Figure 3 is a plot of burn-out as a function of time. The calculation assumes there is no reserve BF_3 in the system.

(n,α) Pressure Increase

In the transmutation of B^{10} under neutron irradiation (*1*), 93% of the product atoms are B^{11}; the remainder are Li^7. Thus, with boron in the form $B^{10}F_3$, it is expected that the following will occur

$$B^{10}F_3 + {}_0n^1 \rightarrow 3F + B^{11*}$$
$$\rightarrow (3F) + He^4 + Li^7$$

Assuming the lithium combines chemically with a fluorine atom and the other fluorine atoms remain in the gaseous state, there will then be three mols (LiF, He, F_2) where there was one BF_3 mol originally.

The LiF is expected to be a solid. It will therefore increase the pressure only a negligible amount. The He and F_2 will doubtless be gaseous. Thus, effectively, there are two mols of gas formed for each mol destroyed. Figure 3 shows how the reaction causes the pressure to rise as a function of time.

From the two sample curves of Fig. 3, it will be noted that if a given pressure is to be maintained in the system by bleeding off the gas as the pressure increases, the control value of the tube decreases not only as a result of B^{10} atoms being burned out but also because some B^{10} will be removed by bleeding. This factor must be considered in control-system design. It indicates that it is probably more desirable to use on-off valves rather than pressure regulators to control the pressure. If two- or three-way solenoid valves are used, they must give a dead-tight shut-off.

Boron Isotope Monitor

Because control strength is reduced and pressure increased during burnout, some measurement other than pressure must be made to determine actual control strength with the gas-type system. It would be most desirable to measure B^{10} concentration, for this is directly proportional to control strength. Figure 4 is a schematic of apparatus that can be used to monitor the B^{10} concentration present in BF_3 at any time.

The feasibility of this type of measurement was confirmed by an experiment using a small radium-beryllium capsule as a neutron source. Paraffin was used to thermalize the neutrons before they passed through a chamber connected to the BF_3 control tube. A neutron counter located above the BF_3 container was used to measure the number of neutrons passing through the gas. As the B^{10} concentration was decreased, the number of neutrons passing through the chamber increased.

Sensitivity of this device can be adjusted by varying the strength of the neutron source, by changing pressure-vessel volume, by varying the paraffin moderator thickness, and by changes in geometry and shielding.

Control Strength

Within the limited pressure range used experimentally with the 305 test reactor, calibration was linear. But if a large pressure variation is used in the control system, the change in reactivity will not be a linear function. A typical curve, in this instance for a BF_3 tube in the center of the MTR tank, is shown in Fig. 5.

The cause of this nonlinearity is

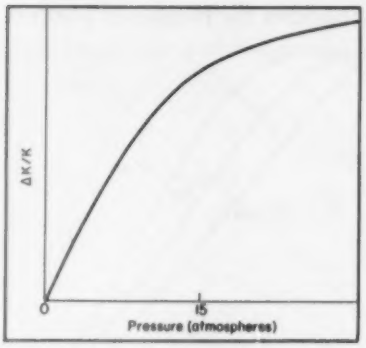

FIG. 5. For large pressure variations in gas-control system, control strength is not a linear function of pressure

shown by the equation

$$\Delta K = C\Sigma_a(\phi_{Local}/\phi_{Max.})^2$$

where ΔK is reactivity change and C is an experimentally determined constant. The macroscopic cross section, Σ_a, varies directly with pressure increase, but the local flux density is reduced as control strength increases. The curve becomes asymptotic at 100% blackness.

Selecting Equipment

Extreme care must be exercised in selecting pressure-control equipment. BF_3 hardens both synthetic and natural rubber and attacks all plastics except those with a fluorine base, such as Teflon. Dry BF_3 does not attack aluminum, steel, brass, or any other of the usual materials used for construction of pressure vessels and valves (*2*). But when BF_3 is passed into water, it is hydrolyzed, and several acidic compounds may be formed (*3*). The formation of specific compounds is a function of the kinetics involved, for the first reaction products may, in time, be solvated. Known reactions and available equilibrium constants are shown at right.

BF_3 solubility in water is of the same magnitude as that of ammonia in water. At 0° C and 762 mm of mercury, 1 ml of water absorbs 1,057 ml of BF_3. At room temperature, the ratio of absorption is 1:700. This very high solubility suggests solvation of the gaseous solute.

Disposing of Irradiated Gas

Free escape of spent gas to the atmosphere would be undesirable for two reasons: (a) it would be slightly radioactive, (b) even dilute concentrations of BF_3 will cause irritation of the skin and throat. There has been no noticeable physical damage to workers employed in the chemical processing plants that produce BF_3, however.

Calculations of induced activity in commercial BF_3 have been made for reactor exposures of 1, 2, and 3 months.

BF_3-Water Reactions

$$2BF_3 + 2H_2O \rightleftharpoons BF_3{\cdot}H_2O + HBF_3OH$$
$$HBF_3OH + H_2O \rightleftharpoons HF + HBF_2(OH)_2{}^{*}$$
$$HBF_3OH + HF \overset{slow}{\rightleftharpoons} HBF_4 + H_2O$$
$$HBF_4 + 3H_2O \rightleftharpoons H_3BO_3 + 4HF$$
$$HBF_4 + H_2O \rightleftharpoons HF + HBF_3OH\dagger$$
$$BF_3 + 2H_2O \rightleftharpoons BF_3{\cdot}2H_2O \rightleftharpoons [H_3O^+][BF_3OH]^- \rightleftharpoons HF + HBF_2(OH)_2$$
$$3(BF_3{\cdot}2H_2O) \rightleftharpoons HBF_2(OH)_2 + HF{\cdot}2BF_3{\cdot}4H_2O$$
$$6HBF_2(OH)_2 \rightleftharpoons 4BF_3 + B_2O_3 + 9H_2O$$
$$HBF_2(OH)_2 + H_2O \rightleftharpoons 2HF + H_3BO_3$$
$$4BF_3 + 3H_2O \rightleftharpoons 3HBF_4 + H_3BO_3$$
$$H_3BO_3 + HF \overset{fast}{\rightleftharpoons} HBF(OH)_2$$
$$HBF(OH)_2 + 3HF \overset{slow}{\rightleftharpoons} HBF_4 + 3H_2O$$
$$H_3BO_3 + 3HF \rightleftharpoons HBF_3OH + 2H_2O$$
$$2BF_3 + 3H_2O + H_3BO_3 \rightleftharpoons 3HBF_2(OH)_2$$

For the over-all reaction of boron trifluoride and water, the equilibrium constant k(liters/mole-min) = $6.4 \times 10^{-3} + 7.35\ (H^+)$ at 25° C.

* $K_{equil} = 1.1 \times 10^{-2}$ at 25° C
† $K_{equil} = 2.3 \times 10^{-3}$ at 25° C

Typically, commercial BF_3 contains 96.2% BF_3, 2.39% SiF_4, 0.4% SO_2, and 0.42% air. It was assumed that a sample was contained in a 1-ft³ vessel at 360 psig. The maximum calculated gamma activity at a distance of 1 ft from the container was 1.4×10^{-3} mr/hr. There are, no doubt, small traces of other impurities in the gas that will increase the activity.

Fortunately, the affinity of water for BF_3 provides an easy method of avoiding its release to the atmosphere. Figure 6 shows how the gas can be disposed of by absorbing it in water. The gas passes through a bubbler, past a check valve, and is absorbed by the recirculating water at the throat of the aspirator.

The final mixture is acidic. Mild steel coupons exposed to this mixture were attacked quite severely, but stainless-steel components were unharmed.

* * *

This article is based on a paper presented at the University of California Conference on Nuclear Engineering, Los Angeles, April 29, 1955.

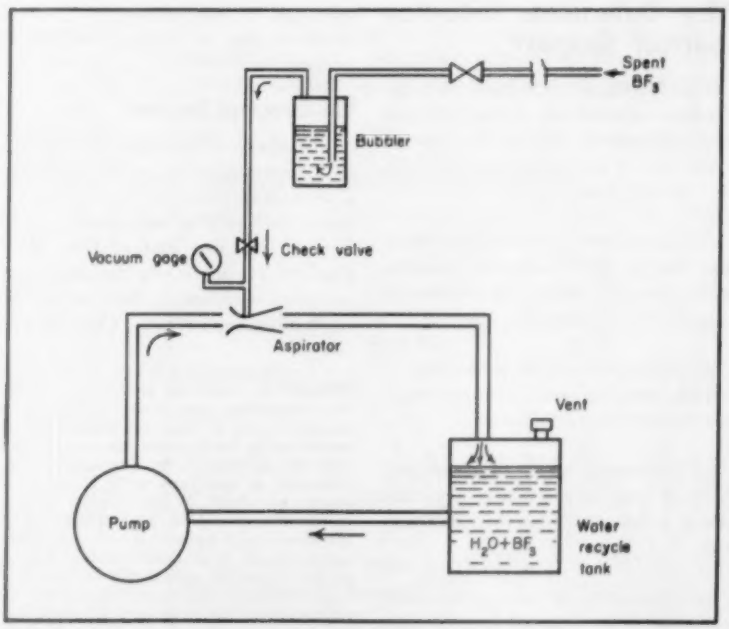

FIG. 6. Safe disposal of BF_3 gas may be accomplished by absorbing it in water

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Here are two schemes for calculating the shape of allowed and first-forbidden beta-ray spectra, given the atomic number of the emitter and the maximum beta-ray energy. Average energy and zero-energy ordinate can also be quickly determined

Calculated Energy Spectra for Negatron Emitters

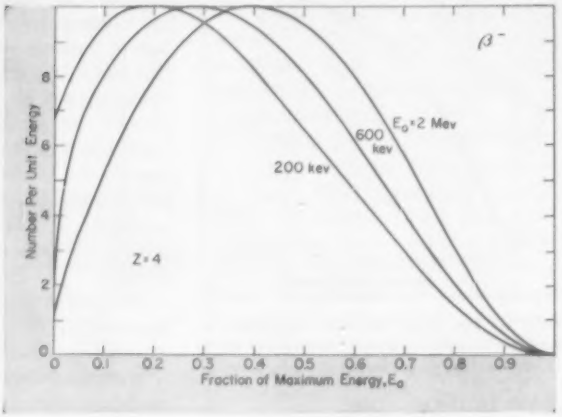

FIG. 1. Allowed negatron spectra; Z = 4; max. energies shown

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How to Figure

IN MANY APPLICATIONS it is useful to know the energy distribution of the beta rays emitted by atomic nuclei. The maximum energy of a beta-ray spectrum, E_0, can be found easily from charts or tables, but the number versus energy distribution, the *shape* of the beta-ray spectrum, is hardly ever given directly in the literature. This article contains graphs from which spectral shapes may be found, given the atomic number of the emitter, Z, and maximum energy, E_0.

Two methods are provided. In Figs. 1–5 the theoretical shapes of allowed beta-ray spectra are plotted for different values of Z and E_0, and a particular allowed spectrum may be found approximately by interpolation. Alternatively, Fig. 6 provides a rapid method for obtaining any allowed shape directly. If graphical accuracy is not sufficient, an allowed spectrum may be calculated directly from tables (*2, 3*).

These theoretical allowed spectra can probably be trusted to give accurate spectral shapes for actual allowed beta-ray transitions. No experimental evidence is included here; for that the reader is referred to the excellent review of beta decay by C. S. Wu (*1*), which discusses the extent of agreement between theory and experiment.*

The theory also appears to be accurate for forbidden transitions, and these are discussed. In some cases, however, the theoretical forbidden spectrum is not unique in that it involves one or several adjustable parameters.

Why Determine Beta-Ray Spectral Shapes?

It is often important to know the shape of a beta-ray spectrum, at least approximately, in order to interpret the response to beta rays of an energy-sensitive detector. Specific examples are:

(a) Rapid determination of the maximum energy of a low-activity beta-ray emitter from its pulse-height spectrum in a scintillation counter.

(b) Estimation of the probability of detecting very low-energy beta-ray tracks in a nuclear track emulsion.

(c) Estimation of the detection efficiency of proportional beta-ray counters having a known energy discrimination level.

(d) Calculation of beta-ray dose and estimation of the effect of forbiddenness upon average energy.

On Spectral Shapes

The shape of an allowed negatron (β^-) spectrum of low maximum energy is perhaps surprising to anyone brought up on the idea that beta spectra are all more or less like that of P^{32}. From Figs. 2 or 3 it can be seen that an allowed spectrum with low E_0 does not exhibit the familiar maximum. This behavior

* A word of warning is in order about the difficulty of obtaining undistorted spectra experimentally: absorption, scattering, or backscattering of beta rays before they are registered by the detector can seriously distort the spectrum. In a magnetic spectrometer, a spectrum with a maximum energy of about 2 Mev begins to show measurable distortion below 500 kev when the source is 3 mg/cm² thick; and a spectrum with E_0 = 160 kev is distorted below about 40 kev by a source 2 μg/cm² thick (*1*). Other types of detectors may not require such thin sources, but it is always difficult in practice to avoid experimental distortion.

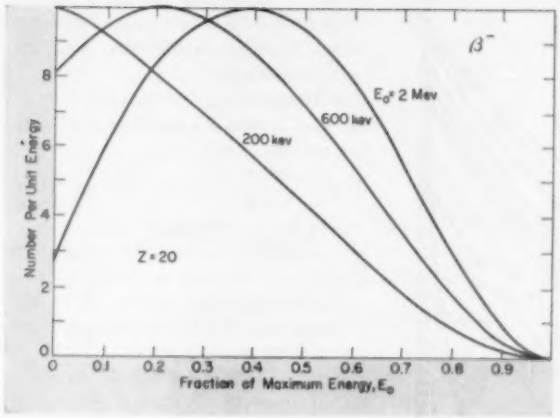

FIG. 2. Allowed negatron spectra; Z = 20; max. energies shown

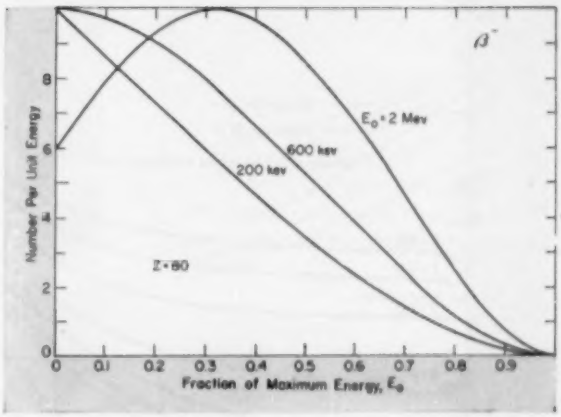

FIG. 3. Allowed negatron spectra; Z = 80; max. energies shown

Shapes of Beta-Ray Spectra

is shown only by negatron energy spectra.

Note that although the number of beta rays per unit energy may remain large as the energy approaches zero, the number of beta rays per unit momentum goes to zero.

This fundamental difference in shape between a beta-ray spectrum plotted in energy units and the same spectrum plotted in momentum units arises from the following facts. When the velocity, v, of a beta ray is small, its kinetic energy is proportional to v^2 while its momentum is proportional to v; hence the number of energy units per momentum unit is proportional to v. For low negatron velocities the number of negatrons per unit momentum is theoretically also proportional to v. Therefore as v approaches zero, the number of negatrons per unit energy remains finite while the number of negatrons per unit momentum approaches zero.

The relatively large number of low-energy beta rays in a β^- spectrum of low maximum energy should be of

Calculated Energy Spectra for Positron Emitters

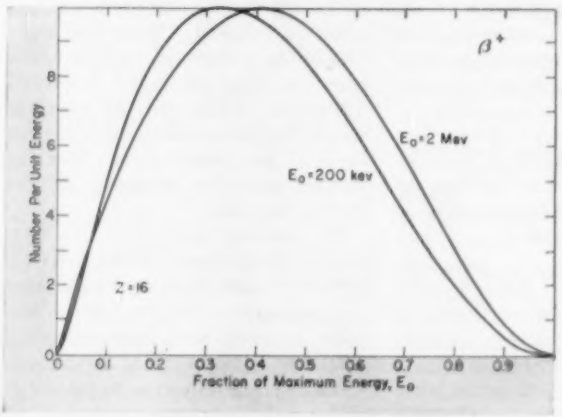

FIG. 4. Allowed positron spectra; Z = 16; max. energies shown

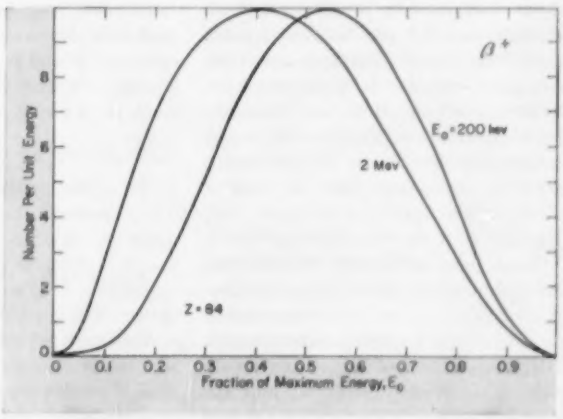

FIG. 5. Allowed positron spectra; Z = 84; max. energies shown

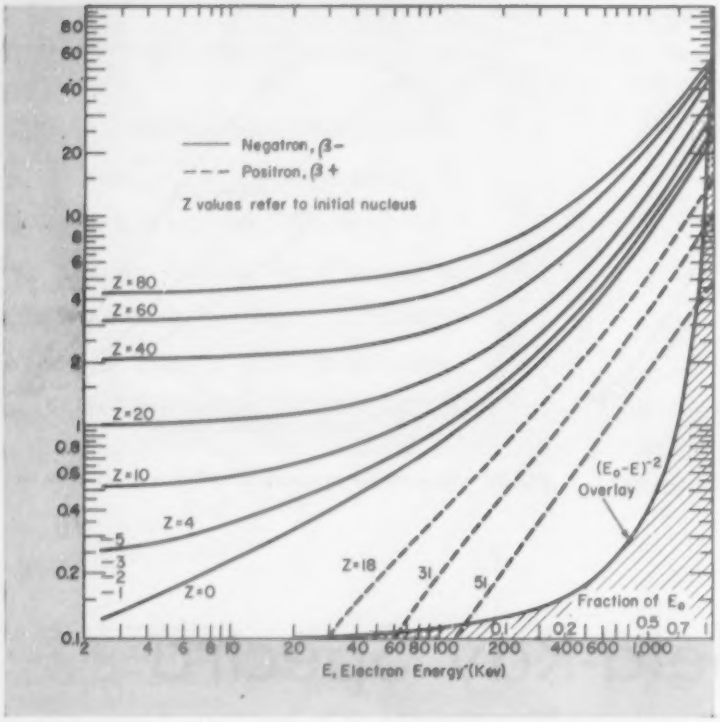

FIG. 6. Graph for obtaining shape of allowed beta spectrum by rapid method. Curves are $pWF(Z,W)$ for various Z. Shaded area is $(E_0 - E)^{-2}$ plotted versus fraction of E_0; it is shown set for E_0 = 2 Mev. An overlay curve should be traced from the shaded area and used as follows: set right edge of overlay (1.0 E_0) at maximum energy of desired spectrum. Then spectrum ordinates are differences between pWF curve for appropriate Z and the overlay measured on vertical log scale

interest to anyone using an energy-sensitive detector.

Determining Spectral Shape

To determine the energy distribution of the electrons emitted from a certain beta-emitting nuclide, first determine whether or not the beta-ray spectrum is complex. If two maximum energies are listed for a beta emitter, then the two beta-ray spectra should be found separately and their ordinates added. If there are conversion electrons from an internally converted gamma ray, they will superimpose line spectra on the continuous beta-ray spectrum. Let us assume that the beta spectrum is simple, having neither of the complications above.

Next, you determine whether the spectrum has an allowed or a forbidden shape. The surest way is to refer to an actual spectrometer measurement. If a measurement of shape is not available, it is often possible to infer the probable shape from the half-life and maximum energy of the beta transition. This is discussed in the section on log ft value.

If the spectrum has an allowed shape it may be found directly from Fig. 6 (as explained in the section on rapid method) or by interpolation from Figs. 1–5. If the spectrum does not have an allowed shape, then the allowed shape for the same Z and E_0 must be multiplied by the shape factor for the particular nuclide. A shape factor is reported in the literature either as an algebraic function of energy or g aphically as in Fig. 9.

Calculation of Figures 1–6

According to the theory of beta decay (*1*), the shape of an allowed spectrum (β^- or β^+) is given by:

$$N(E) = kF(Z,W)pW(E_0 - E)^2 \quad (1)$$

where $N(E)$ = the relative number of beta rays per unit energy

k = an arbitrary constant

$F(Z,W)$ = the Fermi Differential Function (which describes the Coulomb effect on both β^- and β^+ through use of positive and negative values of Z)

$pW(E_0 - E)^2$ = the statistical factor (derived from conservation of energy and momentum between beta ray and neutrino)

E = kinetic energy of beta ray

E_0 = maximum kinetic energy of beta spectrum

$W = \frac{E(\text{in kev})}{510.9} + 1$ = total energy of beta ray in rest-mass units

$p = \sqrt{W^2 - 1}$ = beta-ray momentum

Z = atomic number of initial nucleus (throughout this article, Z is the atomic number of the beta emitter, not of its decay product.)

Exact values of $pWF(Z,W)$ were obtained from the National Bureau of Standards tables of the Fermi function (*2*). These values were corrected for screening using Reitz's Eniac calculations (*3*). Figure 6 shows $pWF(Z,W)$, corrected for screening, as a function of E for both negatron (β^-) and positron (β^+) emitters of different Z. The $pWF(Z,W)$ curves for negatrons become approximately constant at low energy, so for negatron spectra (Figs. 1–3), $N(E)$ remains finite and can be extrapolated smoothly into the axis at zero energy.

All plotted spectra (Figs. 1–5) have been normalized to have a maximum ordinate of 10 betas per unit energy; the accuracy is about 2%.

Rapid Method for Allowed Shapes

From the curves in Fig. 6, one can find the number per unit energy as a function of energy for the beta rays of any allowed spectrum. The method utilizes the movable overlay plot shaded in at the lower right of Fig. 6. A working overlay can be constructed by tracing the overlay curve on thin paper or celluloid. When the right edge of the overlay is set at the maximum energy of the desired spectrum, the number of betas per unit energy is simply the difference between the curve for Z of the parent nucleus and the overlay curve as measured on the vertical log scale.

The overlay curve is $(E_0 - E)^{-2}$ plotted against E/E_0. Both $pWF(Z,W)$ and $(E_0 - E)^{-2}$ are plotted on a log scale so that the vertical distance between them represents the difference between their logarithms. Measuring this difference on the vertical log scale is equivalent to finding the antilogarithm. Algebraically:

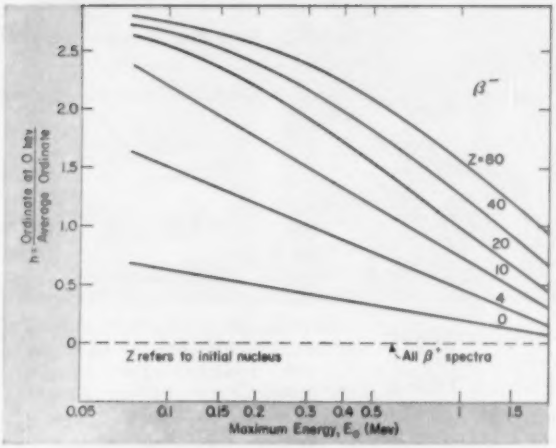

FIG. 7. Zero-energy ordinate of allowed spectra. Zero-energy ordinate divided by average ordinate is plotted versus maximum energy

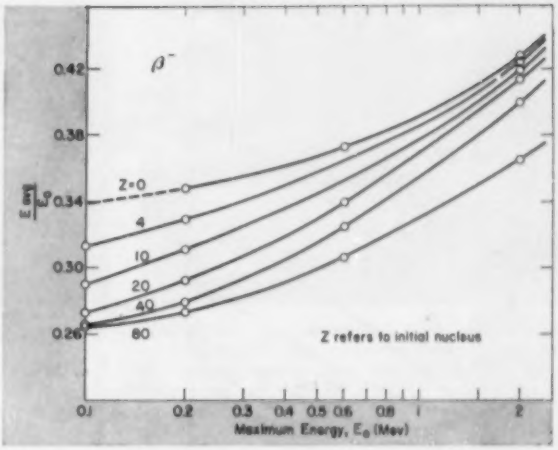

FIG. 8. Average energy of allowed negatron spectra. Average energy divided by maximum energy is plotted versus maximum energy. Circles are values given in Table 1

$$\log N(E) = \log pWF(Z,W) - \log (E_0 - E)^{-2} \quad (2)$$

Now the logarithm of Eq. 1 is similar; it is

$$\log N(E) = \log k + \log pWF(Z,W) + \log (E_0 - E)^2$$

This is equivalent to Eq. 2: changing sign of the last term changes the sign of the exponent. The vertical position of the overlay affects the value of k, the arbitrary constant, and does not affect the shape of a spectrum.

EXAMPLE: Find the allowed β^- spectrum for $Z = 40$ and $E_0 = 2$ Mev:

a) Set the right edge of the overlay ($E = 1.0\ E_0$) at 2 Mev (as in Fig. 6).

b) The difference between the $Z = 40$ negatron curve and the overlay curve as measured with a pair of dividers is $N(E)$:

E (Mev)	$N(E)$
0.1	27
0.4	44
0.8	49
1.5	21
1.8	4
1.9	1
2.0	0

Note that when the Z curve crosses the overlay curve, $N(E) = 1$. When the Z curve is above the overlay curve, the divider separation is measured up from unity, and when below, down from unity, on the vertical log scale.

Zero-Energy Ordinate

The quantity h, the ratio of the zero-energy ordinate to the average ordinate of allowed beta-ray spectra, is plotted in Fig. 7, for different values of Z and maximum energy E_0. The zero-energy ordinate refers to the number of beta rays per unit energy as the energy approaches zero. The average ordinate is the total area under the spectrum divided by the maximum energy; that is

$$N(E)_{avg} \equiv \frac{1}{E_0}\int_0^{E_0} N(E)\,dE$$

$$h \equiv \frac{N(0)}{N(E)_{average}} \quad (3)$$

Values of h from 0 to 3.0 were obtained graphically from the calculated spectra to an accuracy of about 0.1.

The appearance of an allowed beta-ray spectrum can be quickly obtained from this ratio, h. If $h = 0$, $N(E)$ drops to zero at $E = 0$; this applies to all β^+ spectra. If h is large, the spectrum has no maximum but continues to rise as E approaches zero, as the $E_0 = 200$ kev β^- spectrum in Fig. 3. A spectrum intermediate between these two extremes would be a straight line decreasing from ordinate $N(0)$ at $E = 0$ to $N(E_0) = 0$. Since such a straight-line spectrum would have an average ordinate $N(E)_{avg} = N(0)/2$, its h-value would be 2. Therefore none of the spectra with h roughly greater than 2 in Fig. 7 show the familiar maximum.

The ratio, h, is also useful for estimating the detection efficiency to be expected when the threshhold energy of a detector is much less than E_0. Suppose a counter could detect all betas emitted with energy greater than $0.01\ E_0$. Then if the beta spectrum were not distorted (by source thickness, for example), the efficiency of the counter would be about $(1 - 0.01h)$.

Average Energy

The ratio of average to maximum energy for allowed negatron spectra is given in Fig. 8 and Table 1 as a function of Z and E_0. The average energy of a spectrum is defined as:

$$E_{avg} \equiv \int_0^{E_0} EN(E)\,dE \Big/ \int_0^{E_0} N(E)\,dE$$

Values of E_{avg} were obtained by graphical integration of calculated spectra. These values of average energy are within 2% of those of Marinelli *et al.* (*4*) except for very low energy spectra. Below $E_0 \simeq 300$ kev, Marinelli's curves appear to be 5–10% high. (Incidentally, Marinelli gives values of E_{avg} for β^+ spectra that are not included here.)

Shape Factor for Forbidden Spectra

All of the foregoing applies to allowed beta transitions, and all of the spectra given previously are said to have an allowed shape. To find the shape of the beta-ray spectrum for a forbidden transition, first obtain the allowed spectrum for the given Z and maximum

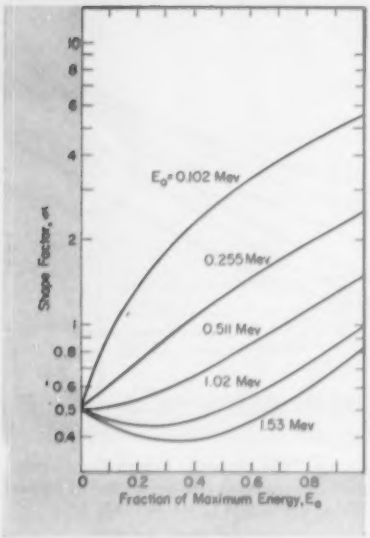

FIG. 9. First-forbidden ($\Delta I = 2$) shape factor, $\alpha \simeq p^2 + q^2$, plotted versus energy for several maximum energies

energy. Then multiply by the proper shape factor, $C(E)$. Rewriting Eq. 1 so that it applies to any beta emitter

$$N(E) = C(E)kF(Z,W)pW(E_0 - E)^2 \quad (4)$$

where $N(E)$ = number of beta rays emitted per unit energy
$C(E)$ = shape factor (a function of energy)
$C(E) = 1$ for any allowed transition

The other symbols are exactly as in Eq. 1. In general, the shape factor for a particular beta transition can best be obtained from experimental articles. The shape factor is usually given in terms of p and q, the beta-ray and neutrino momenta:

$$p^2 = (W^2 - 1)$$
$$q^2 = (E_0 - E)^2$$

where W, E, and E_0 mean the same as in Eq. 1.

The most common forbidden shape factor is that for a first-forbidden transition* with $\Delta I = 2$, often called the α factor:

$$C(E) = \alpha \simeq p^2 + q^2 \quad (5)$$

In Fig. 9, α is plotted as a function of E/E_0 for different maximum energies, E_0. A dozen nuclides known to exhibit the α shape are listed in Table 2, taken from the review article by Wu (*1*). Other transitions believed to be first forbidden with $\Delta I = 2$ (which may be expected to show an α shape) are listed by Mayer (*5*).

Spectral Shape and Log *ft* Value

When no experimental determination of the shape is available, an indication of the probable shape can be found in many cases from the log *ft* value and the spin change.†

If the half-life and maximum energy of a given beta-ray transition yield a log *ft* value (*6*) below 6.0, the beta transition is probably allowed and the beta spectrum may be expected to have an allowed shape, $C(E) = 1$.

If the log *ft* value is between 6.0 and about 10, the transition is probably first-forbidden. First-forbidden transitions may have spin change $\Delta I = 0$, 1, or 2. If $\Delta I = 2$, then the beta spectrum will have an α shape, $C(E) = \alpha$. If $\Delta I = 0$ or 1, the beta spectrum may or may not have the allowed shape. If it differs from the allowed shape, the difference may enhance either the high- or low-energy end of the spectrum and cannot be uniquely predicted as yet.

For log *ft* greater than 10, the transition is probably second or third forbidden. Spectra for which a unique shape factor is known are given by Wu (*1*). A useful classification of some beta-active nuclides according to spin change and forbiddenness is given by Mayer (*5*).

* * *

I would like to thank Miss Virginia K. White for making the calculations of spectral shapes.

This work was supported in part by contract AT (30-1)-952 with the U. S. Atomic Energy Commission.

* First-forbidden transitions involve parity change.

† A rapid graphical method for calculating log *ft* values from half-life, atomic number, and maximum energy is given by S. A. Moszkowski (*6*).

TABLE 1—Average Energy of Allowed Negatron Spectra, E_{avg}/E_0*

Maximum energy, E_0 (Mev)	*Atomic number of initial nucleus, Z*							
	0	*4*	*10*	*16*	*20*	*40*	*49*	*80*
0.1		0.313	0.290	0.278†	0.273	0.265	0.264†	0.264
0.2	0.347	0.330	0.312		0.293	0.279		0.274
0.6	0.374				0.341	0.325		0.307
2	0.428	0.425	0.420		0.414	0.398†		0.376

* Tabulated values are average energy divided by maximum energy, E_0. They should be accurate to within 2%. † These values should be good to within ½%.

TABLE 2—Beta-Ray Spectral Shapes*

ALLOWED SHAPES have been found for

H^3	(*1*)	Cu^{61}	(*1*)
He^6	(*1*)	Cu^{64}	(*1*)
C^{14}	(*7*)	Nb^{95}	(*11*)
Na^{24}	(*8*)	In^{114}	(*1*)
P^{32}	(*8, 9*)	Pm^{147}	(*1*)
S^{35}	(*1*)	Hf^{181}	(*11*)
Ca^{45}	(*10*)	Re^{186}	(*9*)
Co^{60}	(*11*)	Au^{198}	(*9, 11*)

ALPHA SHAPES (First forbidden, $\Delta I = 2$, Yes) have been found (*1*) for

Cl^{38}	Y^{90}
K^{42}	Y^{91}
Rb^{86}	Sn^{123}
Sr^{89}	Sn^{125}
Sr^{90}	Sb^{124}
Sr^{91}	Cs^{137}

* Only a few shapes are given. In many cases these experimental measurements do not extend below about one-third the maximum energy of the spectrum.

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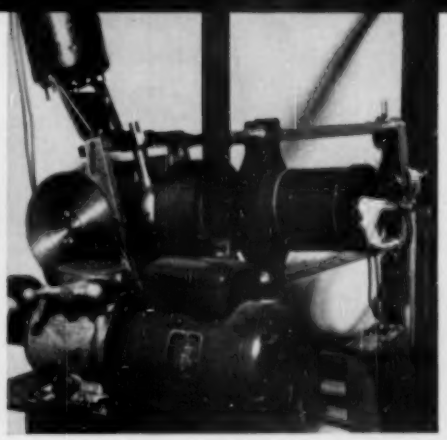
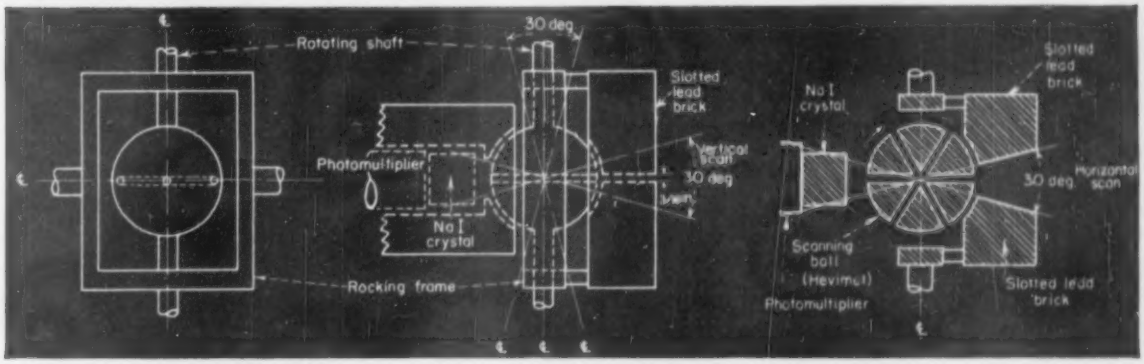
OVER-ALL VIEW. Just behind scanning head is shielded scintillation counter and small CRT viewed by Polaroid-Land camera. CRT spot moves in synchronism with scanning head. See G. R. Meneely, R. J. Kerr, J. E. Hoffman, and S. K. Haynes, *Phys. Rev.* 95, 308A (1954)



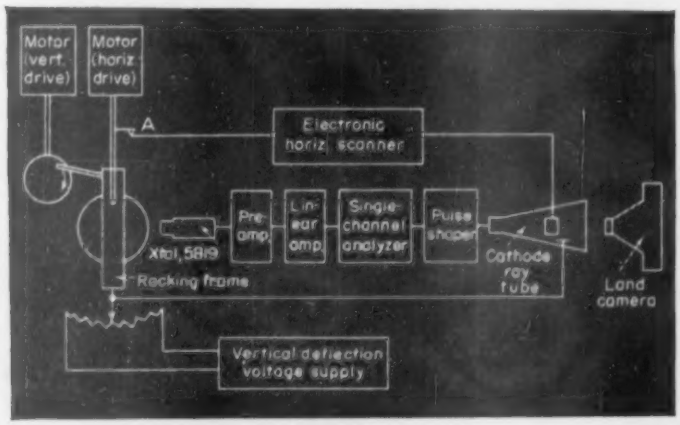
SCANNING FRAME, rocked by heart-shaped variable-speed cam, supports slotted lead brick and rotating Hevimet ball pierced by three equatorial holes

Spinning-Ball CRT Scanner

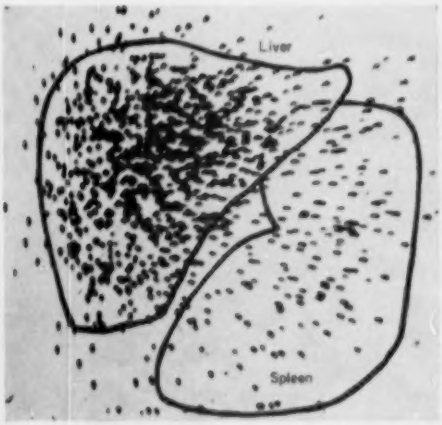
By GEORGE R. MENEELY and HOMER L. JONES, *Radioisotope Unit and Medical Illustration Laboratory of Thayer Veterans Adminstration Hospital and Vanderbilt University, Nashville, Tennessee*



MECHANICAL DETAILS. Slotted lead brick provides additional shielding for detector. Extent of vertical and horizontal scans is indicated; 30-deg rocking motion gives 30-deg vertical scan. Slot and holes in rotating ball give horizontal scan



ELECTRONIC CIRCUITS provide synchronism between CRT spot and scanning head and intensify spot when gamma is detected. Single-channel analyzer discriminates against degraded Compton-scattered gammas from adjacent organs



SCAN OF ABDOMEN after intravenous colloidal Au^{198} . . . most is in liver, but some is in enlarged spleen. Scan required 5 min

TABLE 1—Exposure in Roentgens of 1,000-kvp X-rays to Produce Various Densities

Kodak film	Kodak developer	Roentgens D = 0.5	= 1.0	= 1.5	= 2.0	= 2.5	= 3.0
Super Panchro-Press, Type B	Kodak Rapid X-ray	1.3	4.3	11.	30.	85.	280.
	DK-60a	1.7	7.6	27.	87.	280.	1,000.
Super-XX	Kodak Rapid X-ray	1.4	4.7	13.	35.	110.	440.
	DK-60a	1.9	9.8	38.	140.	470.	1,300.
Verichrome	Kodak Rapid X-ray	1.9	5.4	14.	43.	—	—
	DK-60a	2.1	6.9	22.	83.	—	—
Kodalith Ortho, Type 2	Kodalith	1,100.	1,400.	—	1,700.	—	1,900.

Disaster Monitoring with Amateur and Commercial Photographic Films

By G. M. CORNEY
and H. M. CLEARE
Research Laboratories
Eastman Kodak Company
Rochester, New York

IN THE EVENT of an atomic disaster, widely distributed stand-by dosimeters might be extremely valuable, even if they gave only approximate indications. Photographic films ordinarily stored in commercial stocks and homes might fulfill this need.

With this emergency in mind, the sensitivities to penetrating radiation were determined for several popular films: Kodak Super Panchro-Press Film, Type B; Kodak Super XX Panchromatic Film; Kodak Verichrome Film; and Kodalith Ortho Film, Type 2. X-ray films were not included because their sensitivities to penetrating radiation have been published (*1–3*).

Film Calibration

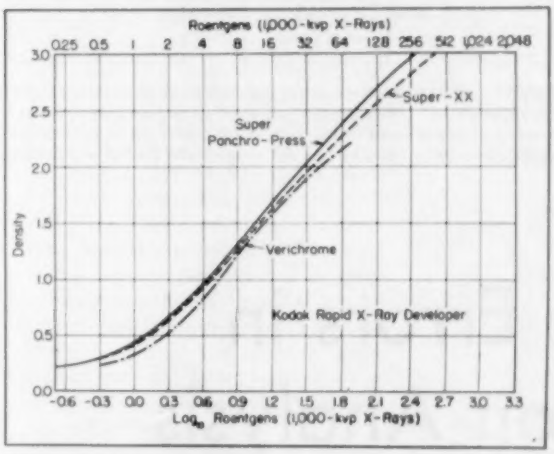
Film sensitivities, in roentgens, were determined for the unfiltered primary radiation from a 1,000-kvp resonant-transformer X-ray machine and were checked with radium gamma rays. These sensitivities also apply reasonably well to radiation generated at voltages up to several Mev and to the gamma rays of radium and cobalt-60, and therefore should also apply to atomic bomb prompt radiation (*4*).

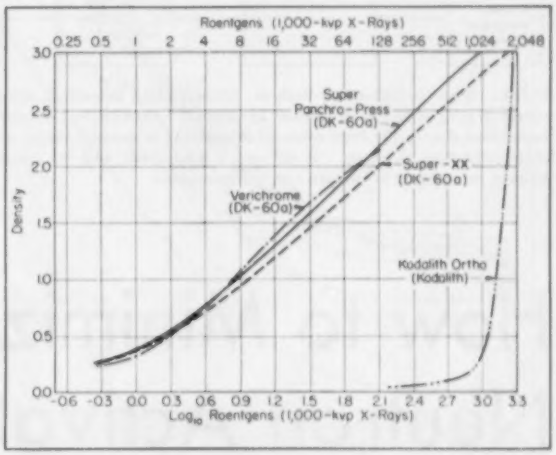
Photographic materials are less sensitive to these hard radiations, e.g., 1,000-kvp X-rays, than to softer radiations. Therefore, calibrations made with 1,000-kvp X-rays would cause softer radiations to be overvalued. Specifically, such a calibration would cause overvaluation of any residual radiation from an atomic bomb (*4*) to which the film may have been exposed. The magnitude of the error would be difficult to estimate. The extent of the exposure to the residual radiation would, in general, be unknown. Further, different types of film vary in their relative sensitivities to hard and soft radiation. Silver-bromide photographic materials would be expected to have a spectral sensitivity curve to X- or gamma rays similar to that given by Wilsey (*1*), but the ratio of maximum to minimum sensitivity depends upon the specific material. Therefore, the dosage values obtained with recovered film should be regarded as "*approximate maximum dosages.*"

To calibrate the films, samples in light cardboard holders were placed at a series of distances from the X-ray focal spot and exposed simultaneously to 1,000-kvp X-rays. The intensity (r/min) for one film location was determined to within 10% (*5*) with a Victoreen condenser-type r-meter. From this, the dosage to each film of a series could be computed. The films were developed in deep tanks, for the times shown in Table 1; fixation, washing, and drying followed normal procedure.

A few points for each film were checked by exposing films to known radium gamma-ray dosages. These agreed with the X-ray measurements to within ±15%. The difference between the two determinations included

Response of Film to 1,000-kvp X-Rays


Roentgens (1,000-kvp X-Rays)
0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048
Density
Super-XX
Super Panchro-Press
Verichrome
Kodak Rapid X-Ray Developer
-0.6 -0.3 0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3
Log10 Roentgens (1,000-kvp X-Rays)


Roentgens (1,000-kvp X-Rays)
0.25 0.5 1 2 4 8 16 32 64 128 256 512 1,024 2,048
Density
Super Panchro-Press (DK-60a)
Super-XX (DK-60a)
Verichrome (DK-60a)
Kodalith Ortho (Kodalith)
-0.6 -0.3 0.0 0.3 0.6 0.9 1.2 1.5 1.8 2.1 2.4 2.7 3.0 3.3
Log10 Roentgens (1,000-kvp X-Rays)

EACH DOSE-DENSITY CURVE represents average of several independent determinations. (Table 1 gives roentgens to produce various specific densities.) Super Panchro-Press Film, Type B, and Super-XX Panchromatic Film, useful up to 300–1,000 r, are preferable for dosage estimates; Verichrome Film cannot be recommended for densities above about 2.0, corresponding to about 100 r of hard X-rays. Very high contrast of Kodalith Ortho Film, Type 2, makes it suitable to estimate only if exposure exceeds 1,000 r. If processed film is clear, exposure was probably $<1{,}000$ r; if black, probably $>1{,}000$ r

the difference in film sensitivity to the two radiations, errors in ionization measurements at 1,000 kvp, and experimental variations.

Practical Considerations

In the absence of a densitometer, estimates of film densities of less than 2.0 may be made with a photoelectric exposure meter, or a Kodak Densiguide may be used for visual comparisons. Such methods are mere stopgaps and are not adequate substitutes for the use of a conventional densitometer.

Monitoring by means of common photographic films recovered from a disaster area will give only approximate results. Dosage evaluations will be performed with films of different ages that may have been stored under widely differing conditions; development techniques will be difficult to standardize under disaster conditions; exposure to relatively soft radiation before and during recovery will affect the results. Despite these sources of error, results of this crude monitoring procedure might prove of value in the absence of more reliable data.

* * *

This article is Communication No. 1695 from the Kodak Research Laboratories.

TABLE 2—Development and Darkroom Illumination Recommendations

Kodak Film	*Development times (min) at 68° F*			*Maximum darkroom illumination*
	Kodak Rapid X-ray Dev.	*Kodak Dev. DK-60a*	*Kodalith Dev.*	
Verichrome	5	7	—	Kodak Wratten Series 2*
Super Panchro-Press, Type B	5	6	—	Total darkness
Super-XX	5	5.5	—	Total darkness
Kodalith Ortho, Type 2	—	—	2.25†	Kodak Wratten Series 1A*

* Kodak Safelight Filter in suitable safelight lamp with a 15-watt bulb, at not less than 4 ft from film.
† Constant agitation.

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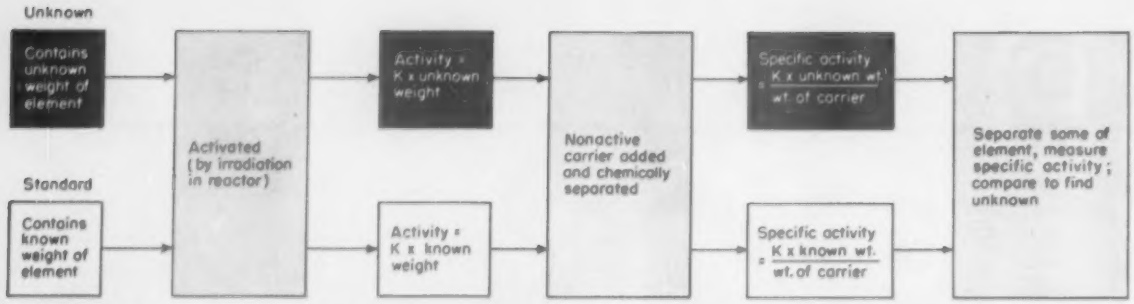
Unknown
Contains unknown weight of element
Standard
Contains known weight of element
Activated (by irradiation in reactor)
Activity = K x unknown weight
Activity = K x known weight
Nonactive carrier added and chemically separated
Specific activity = K x unknown wt. / wt. of carrier
Specific activity = K x known wt. / wt. of carrier
Separate some of element, measure specific activity; compare to find unknown

FIG. 1. Steps in activation analysis: Samples and standards are irradiated together to produce active isotopes of element being determined in proportion to its amount in sample. Activation is usually by (n,γ) reactions. After irradiation, some of radioactive element is separated chemically from other radionuclides in sample, along with carrier quantity of inactive element, under conditions to yield radiochemically pure product. Its activity is measured, and by comparing specific activity (activity per unit weight) with that of a standard, amount of element in sample can be calculated

How to Minimize Errors in Neutron Activation Analysis

To achieve accuracy as well as precision in neutron activation analysis watch out for: errors in activity measurement, incomplete chemical separations, radioactive contamination in carrier, and errors in activation due to competing transmutations, flux inhomogenities, and self-absorption

By ROBERT C. PLUMB and JOHN E. LEWIS
Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pennsylvania

ACTIVATION ANALYSIS has been received with much enthusiasm as a technique of analysis capable of extreme sensitivity. Three recent articles have reviewed specific applications (*1*, *2*, *3*).

The literature on activation analysis has been replete with descriptions of analyses that have demonstrated high sensitivity together with adequate precision. However, Smales (*1*) has provided the only comprehensive review of the limitations of activation analysis.

The general process of activation analysis is outlined in Fig. 1 and its caption. This article considers the errors that may enter at various steps in the process, starting with the last.

Activity Measurements

Geiger-Mueller activity measurements for purposes of activation analysis have been very adequately reviewed by Kohman (*6*). The principal causes of errors in activity measurement are: self-absorption, scattering, geometric errors, radioactive decay, background, and instrumental errors. The instrumental errors are usually manifested as lack of proportionality between actual decay rate and measured counting rate. With the exception of the decay and nonlinearity corrections, these measurement errors may usually be circumvented by comparison methods of counting in which homogeneous samples (as nearly identical in size and shape as possible) are used with reproducible positioning in the counter. Counting needn't be absolute, with corrections for self-absorption, scattering, and geometry, as long as suitable standards are irradiated with the sample.

In general, the problems of self-absorption, scattering, and instrument nonlinearity are less important in scintillation counting of gamma radiation than when measuring beta radiation with the usual G-M detector.

Chemical Separation

There are two general types of errors that may enter in the chemical separation. These are:

1. The carrier added to facilitate chemical separation of the trace element being determined must exchange completely with the radioactive isotope of the element or must be in the same chemical form. If one or the other of these conditions is not met, the chemically separated product may not contain the same ratio of active to inactive element that was in the entire system.

2. The separated isotope must be radiochemically pure in order for the activity to be easily related to the amount of the particular radioactive isotope in question.

Smales (*1*) has pointed out the possibility of determining radiochemical purity by decay measurements and by absorption measurements of the energy of the emitted radiation. The characterization of the isotope by its energy may be accomplished by the Feather (*7*) method or by simply comparing the absorption curves of a sample of doubtful purity with those of one of known purity.

One modification of the usual absorption plot which has been found useful is illustrated in Fig. 2. In the upper portion of the graph, the absorption curves for a set of samples are plotted directly in the usual fashion. Two of the curves are for pure antimony (Sb) metal samples, and the rest of the curves are for Sb separated from irradiated Al alloys. No difference between them is readily discernible.

The lower set of curves shows the same experimental results plotted as the relative activity of the various specimens on a logarithmic scale. The differences between the Sb-metal samples and the Sb separated from alloy samples are striking in this plot. The differences between the curves indicate that the Sb from the "pure metal" and that from the several alloy samples do not have the same radiochemical purity. The problem is resolved in the section "Complications with antimony" on p. 45.

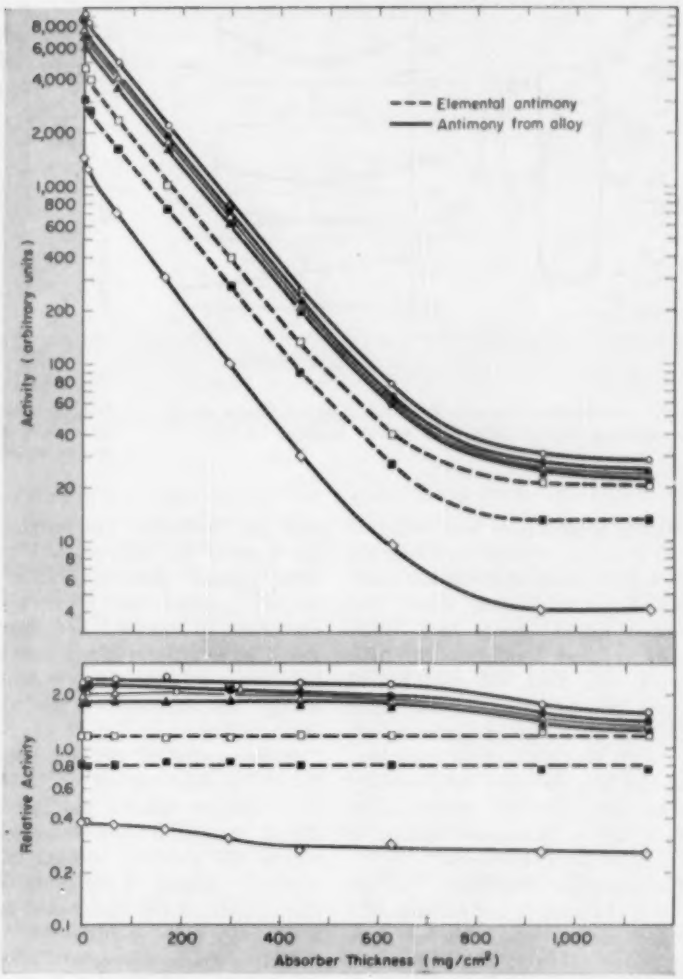

FIG. 2. Absorption of radiation from radioantimony in activated samples plotted as is usual (top) and as relative activity compared with elemental radioantimony

Activation Errors

It is convenient to catalog the possible sources of error in activation into (a) transmutation effects and (b) flux-variation effects. Flux variations may result from either inhomogeneities in the unperturbed flux incident on the irradiation unit or as a result of attenuation of neutrons by material in the irradiation unit.

Some of the errors possible in the

Spectrographic Analysis—A Historical Example

The development of neutron-activation analy is parallels that of spectrographic analysis somewhat, and one may profit by reviewing it. Following Bunsen and Kirchoff's original paper in 1860 (4), "Analysis by Means of Spectral Observations," there was a flurry of activity to develop the new method of chemical analysis. An extreme sensitivity was reached when Hartley (5), in 1884, demonstrated that magnesium could be detected at a concentration of one part in 10^{14} by the spectrograph. It was not until the nineteen twenties that instrumental developments overcame difficulties in reproducibility and permitted the analyst to take advantage of any large part of the sensitivity of the spectrograph. From that time on, emission spectroscopy has flourished as a routine analytical control and research tool. However, within the last decade or two, new limitations in the form of matrix effects have appeared on the validity of spectrochemical analysis, and one is forced to conclude that the accuracy of spectrochemical analysis is not usually as good as its precision. It is usually found that the accuracy depends not only on how well calibrated the spectrochemical standards are, but on how well they simulate the composition and properties of the samples.

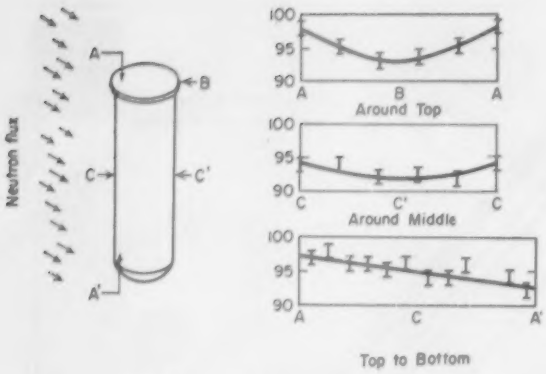

FIG. 3. Distribution of neutron flux incident on irradiation can in hole near reflector of ORNL X-10 reactor (position 14-Z-21)

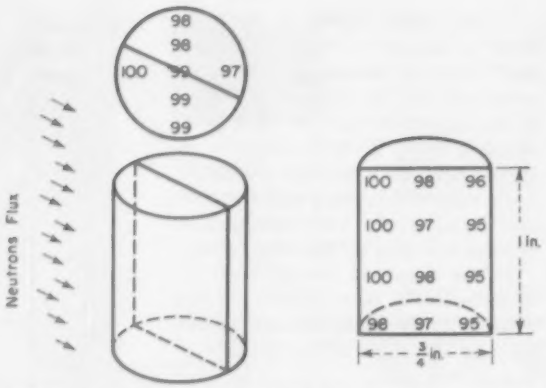

FIG. 4. Low self-absorption in 7075 Al alloy is demonstrated by activity distribution; no effects other than those of flux inhomogeneity considered in Fig. 3 are shown

activation process have been indicated in the literature (*1*), but very little has been written about experimental measurements demonstrating when, and to what extent, errors may enter. Smales (*1*) and Leddicotte (*2*) have pointed out that self-shielding of samples from a neutron flux may occur with large quantities of elements with very high neutron-capture cross sections and have discussed the possibility of transmuting a foreign element in the sample into a radioactive isotope of the element being determined.

Transmutation reactions. The absorption of a neutron and emission of a charged particle usually occurs with high-energy neutrons and, with only a few exceptions (e.g. $Li^6(n,\alpha)H^3$), would not interfere in activation analysis if the irradiation flux consisted solely of thermal neutrons. In practice, however, this condition is not realized.

One case involving the effect of the Al^{27} $(n,\alpha)Na^{24}$ reaction on determining the Na content of Al alloys by means of the Na^{23} $(n,\gamma)Na^{24}$ reaction has been described (*3*). It was found that the contribution of Na^{24} from the transmutation varied greatly with position in the ORNL graphite reactor (and the consequent variation in neutron spectrum). The contribution was 0.015% Na equivalent at a high-flux central position and as low as 0.0002% Na equivalent at low-flux positions near the reflector. This shows the wide variation in neutron energy distribution that may be encountered in various positions of a reactor and suggests that the low-flux positions are more useful for activation analysis employing (n,γ) reactions than the high-flux positions. The striking dependence of the (n,α) reaction on reactor position suggests that a convenient method for detecting the occurrence of transmutation reactions would be to perform irradiations in at least two positions of different neutron-energy distributions to see if the results differ.

Homogeneity of the unperturbed flux. The unperturbed flux of neutrons striking samples and standards during irradiation must be uniform to within the precision desired in the analysis. Results of one study of the homogeneity of the unperturbed flux in a relatively cool low-flux region of the ORNL graphite reactor are given in Fig. 3. The relative flux at different positions on the inside surface of the irradiation can was determined by irradiation of a can containing only a thin liner of specially rolled high-purity tin foil. A grid system was scribed on the foil after activation, it was cut up, and the activity at various positions determined. There was a 6% difference from one side of the can to the other and a 5% difference from top to bottom. The over-all pattern makes it appear that most of the neutrons came from one side of the can and slightly above it.

The poor homogeneity of the unperturbed flux in position 14-Z-21 is probably not representative of the general situation in that reactor but results from the rapid fall-off of flux close to the reflector. The contribution of this type of error may be reduced to a negligible value by a simple correction process. The variation of the unperturbed flux in this position has been found to be reproducible on successive one-week irradiations.

Sample-packaging effects. One factor that can cause variation of the flux within an irradiation unit is attenuation of neutrons by the material used in containers for salts, samples, standards, etc. The relative flux on three NaCl samples irradiated in one irradiation can but in three different packaging materials was as follows,

Container	*Relative flux*
1100 Al alloy tube	100%
Quartz vial (1-mm wall)	95%
Vycor vial (1-mm wall)	84%

No attenuation by Al at thicknesses up to 2 cm has been observed.

Self-absorption. Attenuation of the neutron flux by the samples themselves makes the inside of the samples less active than the outside. The most direct experimental manifestation of this is the dependence of specific activity on sample size.

Keyes (*9*) and others (*10, 11*) have developed equations for the attenuation of monoenergetic neutrons by capture in samples. The relationship for a sphere of dimensions small compared with the mean free path of neutrons in the scattering medium is

$$f = \frac{3}{4}N\sigma a \qquad (1)$$

where f is the fractional decrease in the average flux on a sample, N is the number of atoms per unit volume of the sample, σ is the neutron capture cross section for the particular energy, and a is the sample radius in centimeters.

Unfortunately, without a measure of the neutron energy distribution under the irradiation conditions and with only rather imprecise values for cross sections as a function of energy, it is difficult to predict the sample size that could be used for a given element. The situation is further complicated by (n,γ) capture resonances for neutrons in the electron-volt energy range. These capture resonances can not only be the mechanism for production of most of the radionuclide being measured, but also cause most of the flux attenuation. In general, because of inadequate resolution of neutron monochromators, cross sections at the resonance energies are not known.

Several experiments have been carried out to determine under what conditions attenuation effects may enter in the determination of trace elements in Al. In order to determine if there is any attenuation by Al samples, a split cylinder of 7075 Al alloy (representative of a highly alloyed commercial alloy) was irradiated in a low-flux position of the ORNL graphite reactor. The yield was primarily radioactive Zn^{65}. The cylinder was then sectioned and the specific activity mapped to give the results shown in Fig. 4. The flux was found to vary over the cylinder dimensions, but the pattern checks well with the variations of the unperturbed flux shown in Fig. 3 and does not indicate any attenuation by 7075.

Complications with antimony. In the development of a method of activation analysis for antimony (Sb), it was found, as shown in Fig. 2, that elemental Sb used as primary standards yielded a product that did not give the same type of radiation as the Sb separated from Al-alloy samples. It was concluded that either the samples or standards were not radiochemically pure, but repeated purification did not improve them. The difficulty was finally traced to an attenuation effect in the elemental Sb. Figure 5 shows the total neutron cross section for Sb as a function of neutron energy in the range of 0.01–100 ev. Note the resonance peaks at 5, 15 and 21 ev. These are associated with captures for the Sb^{121} (n,γ)2.8d Sb^{122}, $Sb^{121}(n,\gamma)$3.5min Sb^{122}, and the $Sb^{122}(n,\gamma)$60d Sb^{124} reactions, but have not been assigned.

To determine how these resonances affect specific activity as a function of sample size, approximately spherical samples of Sb ranging in size from less than 100 μg to more than 300 mg were irradiated and their specific activities compared. It is seen from Fig. 6 that the specific activity of a 10-μg piece of Sb differs from one of "zero" weight by 2%, and a 100-mg sample is low by 32% in one reactor position and by 19% in another position. After the Sb^{122} had decayed away, an approximately linear plot of specific activity with radius was observed.

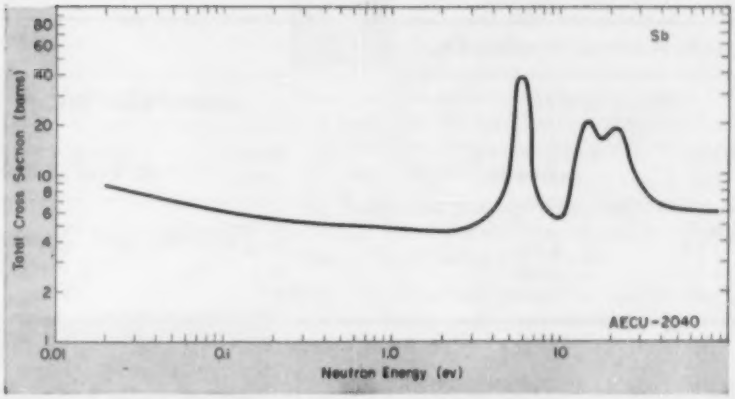

FIG. 5. Total neutron cross section for antimony

The data fit Eq. 1 provided that the attenuation by the two isotopes of Sb are considered separately; that is, the curves obtained shortly after removing the sample from the reactor are resolvable into two curves (one for Sb^{121} and one for Sb^{122}), each of which fits Eq. 1.

Attenuation effect for Sb^{121} is much greater than that for Sb^{123}. This would result in Sb^{122} being produced in a smaller proportion to Sb^{124} in large samples than in small samples, and explains the lack of radiochemical purity demonstrated in Fig. 2. Note that the error on large samples is greater in high flux than in low.

Antimony has only a 6.4-barn absorption cross section for *thermal* neutrons, and one would not have predicted that an effect would enter. Most of the common elements show resonance peaks at neutron energies below a few kev that could be troublesome.

Sodium. Sodium has a total cross section of 3 barns up to 600 ev, a broad resonance peak at 2.7 kev, and a series of peaks above 10 kev. To determine whether there were any appreciable attenuation effects in NaCl, 0.4–100-mg samples were irradiated at high and low fluxes and their specific activities compared. The results, given in the table on p. 46, show a difference of nearly 10% between small and large samples. The differences were not sensitive to the differences in neutron energy distribution, since the results found in the two positions of the reactor were similar. This demonstrates that with even relatively low capture cross sections below the kev range, attenuation effects may enter.

It is unlikely when dealing with most trace elements in samples that there would be a sufficiently high effective cross section (atomic cross section times mole per cent) to result in serious attenuation within the sample. However, the matrix of the sample can contain a highly absorbing element in concentration sufficient to shield out some of the neutrons most effective in activating the element being determined. For example, as shown in Fig. 7, the specific activity of 6062 Al alloy containing 0.73% Cd is 7% less for samples larger than 100 mg than for a "zero-weight" sample.

Standardization procedures. Since it is very difficult to predict attenuation errors and make a correction for them, it would seem desirable to include in every program of activation analysis one phase designed to study these effects. When dealing with elements at fractional per cent concentrations in a matrix such as Al, which is transparent to neutrons, this would involve studies of how best to prepare primary standards.

If one considers activation analysis as a simple comparison method analogous to other instrumental methods of analysis, the standards can be samples of the matrix that have been calibrated by wet chemical techniques. Just as

Specific Activity of Irradiated NaCl

Position 14-Z-21		*Position 14-B-6*	
Weight (mg)	*Specific activity (arb. units)*	*Weight (mg)*	*Specific activity (arb. units)*
0.47	2,240	0.48	1,460
0.73	2,190	3.52	1,350
8.2	2,080	12.3	1,320
21.5	2,040	72.7	1,315

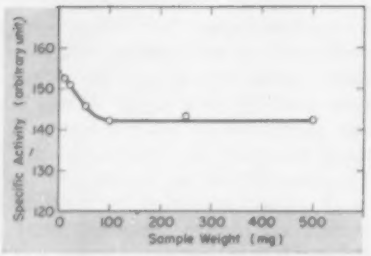

FIG. 7. Specific activity of 6062 Al alloy with 0.73% Cd as function of sample size

with spectroscopic analysis, this should provide a very useful tool, since the element being determined may be $\frac{1}{1000}$ or less of the concentration which is in the calibrated standard and may be far below the limit of detection by other methods of analysis.

This is, however, a very limited application, and activation analysis should be capable of being used on a par with wet chemical analysis as a method of direct comparison against the usually accepted primary standards, pure salts or elemental substances.

The problem then becomes one of preparing standards that will yield a product having the same activity per weight of the element as will be produced in the sample. There are two distinct experimental approaches:

1. A synthetic standard might be prepared by admixing the element with a matrix having a size and composition simulating that of the sample. It may be expected that prohibitively large blanks and sampling effects will sometimes preclude this procedure. Since, in general, it would be difficult to simulate the entire chemical composition of the sample being analyzed, it would usually be necessary to vary the weight of the sample and the standard over wide limits to see if the observed specific activity in the standard could reasonably be expected to be the same as that in the sample.

2. The second approach for achieving experimental results of sufficient quality to merit their use in primary standardization would be to use sufficiently small quantities of the primary standard salt or element so that there would be no attenuation effect. The procedure would then be to determine the dependence of specific activity on the size of the standard, irradiate sufficiently small standards together with samples, and determine if the activity of the sample of finite size yields the same specific activity as a sample of zero weight.

There are several procedures for preparing a standard sufficiently small to preclude attenuation. Weighing on a torsion or beam-type microbalance permits standards of 100 μg or less to be used with 1% accuracy. A second procedure is simply evaporating aliquots of large samples on thin foil. A third technique would be to electroplate the standard element on a large piece of foil—this would provide a sufficiently large quantity of the element to weigh but would distribute it in a geometric form which would minimize attenuation.

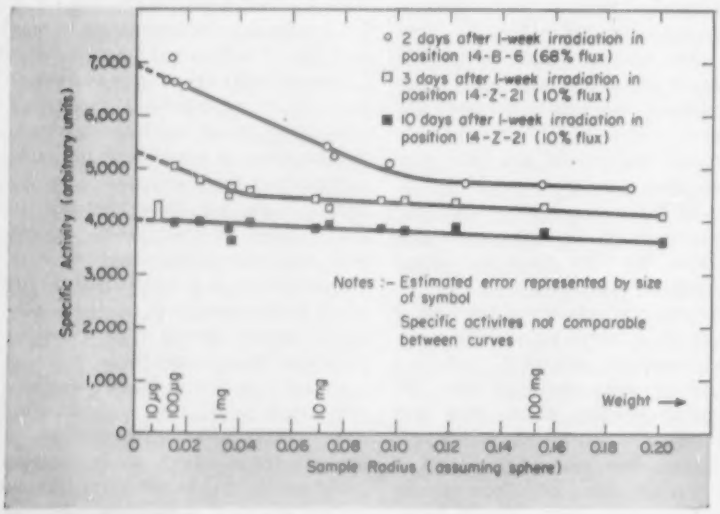

FIG. 6. Variation of specific activity of metallic Sb with size

Conclusions

It is concluded that activation analysis is subject to rather serious limitations in accuracy under certain conditions. However the sources of error thus far detected appear to be avoidable by proper experimental conditions. Activation analysis appears to be capable of sufficient accuracy to make it useful to supplement wet chemical methods of primary standardization at concentrations below the sensitivity of chemical techniques.

* * *

We wish especially to acknowledge the aid of R. H. Silverman of these Laboratories; without his careful chemical analyses and comparison of results, the errors which led to this work would not have been detected.

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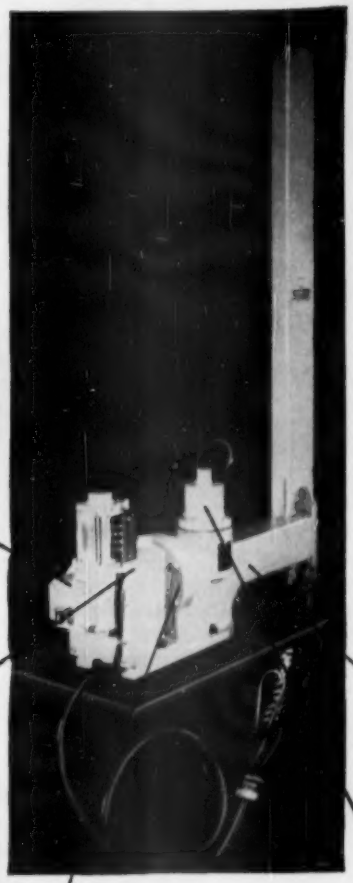

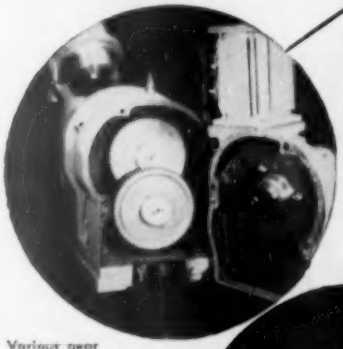

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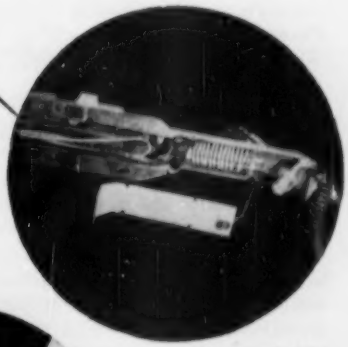

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FIG. 1. Scanner includes drive-motor assembly plus paper-feed and take-up reels

Automatic Paper-Strip Scanner for Detecting Radioactivity

By DAVID V. COHN, G. W. BUCKALOO, and W. E. CARTER

Radioisotope Unit
Veterans Administration Hospital
Kansas City, Missouri
and Department of Pharmacology
University of Kansas Medical Center
Kansas City, Kansas

Several instruments have been described that automatically scan paper chromatograms for detecting radioactivity (*1–5*). Unfortunately, difficult machining and engineering techniques, or the inability to scan more than a few feet of paper without attention, complicate construction or use of several of these instruments. A simple device adapted from the drive mechanism supplied with a commercial densitometer (model 525 Electronic Densitometer, Photovolt Corp., New York) overcomes these objections.

The apparatus (Fig. 1) consists of a Plexiglas channel set into the absorber or sample-slide slot of a Tracerlab G-M or scintillation lead shield. The paper is pulled through the channel by a rubber-tired wheel attached to a synchronous clock motor. A hinged bracket holds the motor on the channel and a loop of rubber tubing serves to prevent slippage of the wheel on the paper. An opening is provided on the top surface of the channel to hold a lead absorber with a slit of desired aperture. The channel is inserted into the shield so that the slit is directly under the detection device. Output from the latter is fed to a ratemeter and thence to a chart recorder.

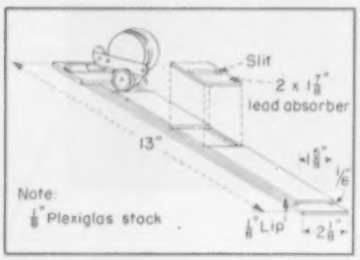

FIG. 2. Dimensions of Plexiglas channel

The channel sections are cut from Plexiglas sheet and glued together (see Fig. 2). The synchronous motor with integral gear train (Haydon Manufacturing Co., Torrington, Conn.) can be obtained in at least three speeds (1, ½, or ⅙ rpm). A drive-wheel hub may be fabricated from plastic or metal and covered with a miniature rubber tire (motor-drive mechanisms with wheel and mounting bracket are available in a variety of speeds from Photovolt Corp.). Alternately, a Singer sewing machine bobbin-rewind wheel and tire may be mounted on the motor shaft with a plastic cement. By selecting the proper diameter wheel or reducing the diameter of the tire, paper speed may be obtained that exactly matches that of the chart recorder.

For continuous scanning, the chromatograms are spliced together with cellulose tape. To facilitate matching chromatogram to chart record, "indexing" spots of a mixture of a radioisotope and a dye may be placed ahead of the starting line and following the solvent front of each chromatogram. If desired, a paper-feed reel and a weight-powered take-up reel may be used (see Fig. 1). The speed of paper and size of absorber slit must be determined in each application for optimal results.

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Effect of Highly Radioactive Solutions on Glass pH Electrodes

By JAMES H. PANNELL*

Chemical Technology Division
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In the chemical processing of fission products, there is occasionally a need for close control of pH, for example in ion-exchange separations. This control should be most easily obtained by means of standard electrodes installed

in the appropriate tanks. However, there was some question as to the life expectancy of the glass electrode when immersed in solutions containing radioactive substances at concentrations of the order of curies per milliliter.

A variety of Beckman glass electrodes was tested by continuous exposure in an acid solution of Ce^{144}-Pr^{144} having a total activity of about 0.4 curie/ml. To avoid contaminating the reference electrode, a salt bridge terminating in an L and N junction (Corning 881 sealed into the tip of a Pyrex tube) was employed. A Beckman model RX electrometer, connected to the electrodes with 25-ft leads, gave continuous indications of *p*H. As the solution was suffering continuous radiation decomposition, however, its *p*H changed continuously so that periodic standardization with buffer solutions was necessary to check performance of the electrode.

The first electrode tested was an older type, similar to model 8990. After 44 hr of exposure, corresponding to a dose of 12×10^6 equivalent roentgen, it showed a 0.10-volt drop of emf in about 1 hr. The reading was moderately steady, but erroneous, for an additional 36 hr, at which point exposure was stopped. After thorough cleaning in acid, the electrode still gave excessively high *p*H readings in buffer solutions of *p*H 2.0 and 7.0. Its d-c resistance, however, was 200 megohms, the same as before irradiation. As this electrode was of unknown vintage, but had obviously seen prior service, one can not conclude that the radiation dose alone was responsible for its failure.

The second and third electrodes tested were Beckman type 1190-80, a general-purpose model of sturdy construction. Electrode number 2 performed well for eight days at *p*H 1.0, but then exhibited a sudden increase in emf, corresponding to *p*H 0.0, after which it indicated gradually a still lower *p*H. After cleaning and soaking in 0.1*N* HCl, the *p*H indicated was still too low. Electrode number 3 also was satisfactory. After operating continuously for three days, it gave a reading within 0.15 of the true *p*H (2.00) on buffer solutions. Exposure of this electrode was stopped after six days.

The fourth electrode to be tested was a type 290-1 with a small tip. It was tested for only four days, during which it performed satisfactorily. If it were necessary to limit the dose received by an electrode, this one in combination with a small volume of solution could be utilized.

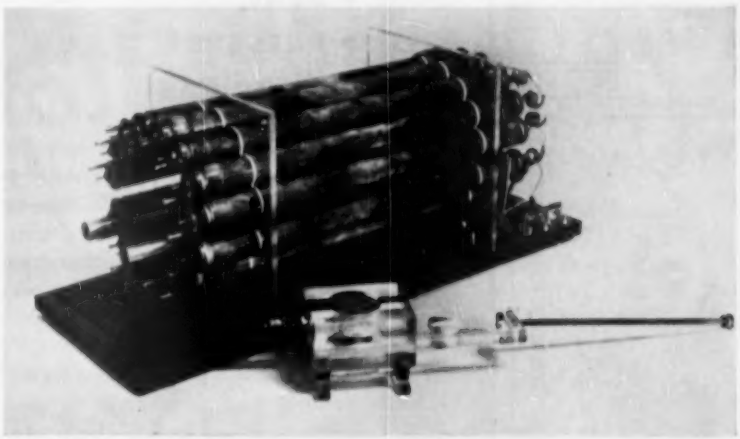
Darkening of the glass electrode tip where it was exposed to the activity was visible in all cases after an exposure of 1 hr. However, this evidently does not indicate serious damage.

It is concluded that glass *p*H electrodes of the types tested would perform satisfactorily for at least one or two days in solutions containing 1 curie/ml. Further work is needed to learn the effects of longer periods and higher levels of irradiation.

* * *

This article is abstracted from unclassified Memorandum CF 52-4-156.

* Work performed while an employee of American Cyanamid Co. on loan to Oak Ridge National Laboratory. Present address: Technical Operations, Inc., Arlington, Mass.



BETA COUNTER with outer plastic housing and lead shielding removed. In use, Lucite counter housing, shown in front of main unit, is within anticoincidence ring, and is removed by sliding along stainless-steel track

Low-Level Beta Counter for Routine Radiochemical Measurements

By HERBERT L. VOLCHOK* and J. LAURENCE KULP†

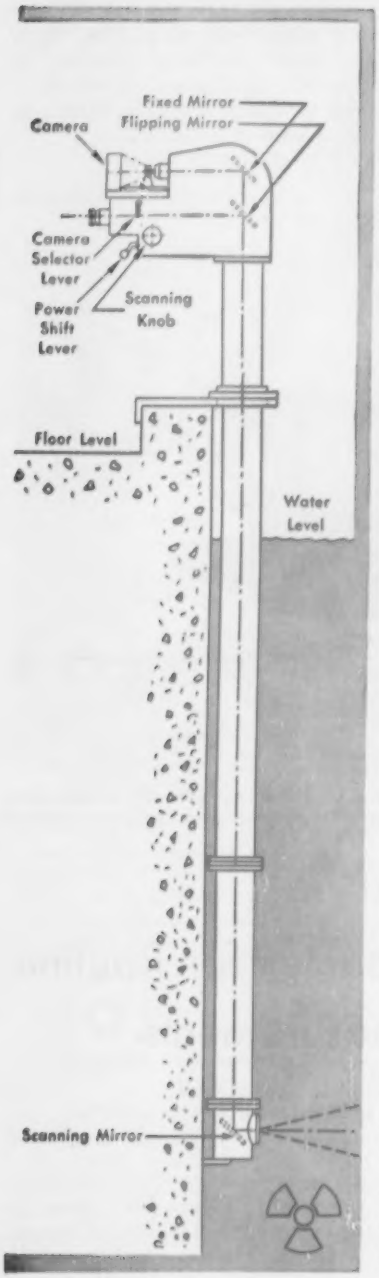
In many beta-counting problems there is a need for a versatile low-background counter. Such a counter, designed initially for the routine measurement of Y^{90} (2.2 Mev), is described here (see illustration). It is useful for very low activity measurements for all but the softest beta emitters. Cosmic-ray and gamma-ray shielding are employed.

The counter employed is a halogen-filled flat G-M counter (Anton model No. H-1007) with a 1-in.-diameter mica window. The counter is sealed within the Lucite housing. The center wire is connected to a single BNC cable connector mounted on the counter housing. A short flexible cable runs between this connector and another on the base of the housing. Careful machining of the Lucite has resulted in the mica window of the counter being at a constant distance of about 2 mm from the top of the sample.

The samples, which are mounted on

* Isotopes, Inc., Westwood, N. J.
† Lamont Geological Observatory, Columbia University, Palisades, N. Y.

UNDERWATER PERISCOPE



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brass disks, fit into the receptacle in the Lucite slide of the housing. A stop on the slide seats the sample accurately under the counter window when the slide is pushed in as far as possible.

A 2-in. lead shield is sufficient to cut out all but the high-energy gamma rays. Most of the latter are canceled by the cosmic-ray shielding—a ring of counters (Radiation Counter Laboratories model 52-12 cosmic-ray counters) in anticoincidence with the sample counter. The over-all length of these tubes is $15\frac{1}{8}$ in.; the active anode length is 12 in. The pig tails on the far ends of these tubes are connected in parallel by a copper ring, which in turn is connected to the rear BNC connector seen in the illustration.

In counting position, the Lucite housing is seated in the center of the anticoincidence ring, the long handle projecting about 2 in. from the front of the unit. By merely pulling the handle, the sample slide moves forward and the Lucite housing emerges from the ring. Sample changing is then a rapid and simple procedure; neither the beta-counter nor anticoincidence voltages must be turned down, nor must any cable be disconnected.

The plateau for this counter is about 100 volts long with a slope of about 0.1%/volt. The over-all efficiency of these counters with a thin source of Y^{90} is 24%. With the lead and anticoincidence shields in place, a background of 1.22 ± 0.03 cpm has been constant for a period of months. Without the anticoincidence shield and with only the lead shield, background was 7 cpm; and with no shielding, 16 cpm.

Sensitivities (counts over background) at which $\pm 10\%$ accuracy is attainable are 1.2, 0.7, and 0.5 cpm for counting times of 6, 12, and 24 hr.

A model has been constructed in which four Anton counters are placed inside the anticoincidence ring. This is economical since only the one ring and one reject circuit are required for four sample counters. The reject pulses are fed into four separate anticoincidence circuits with four transmit channels. Beta-gamma emitters require the single-counter unit to avoid affecting the background of other samples.

* * *

This work was supported by the U. S. Atomic Energy Commission under contract AT-(30-1)-1656. The authors wish to thank W. Tamminga and R. Janes for their technical assistance in the mechanical and electronic construction.

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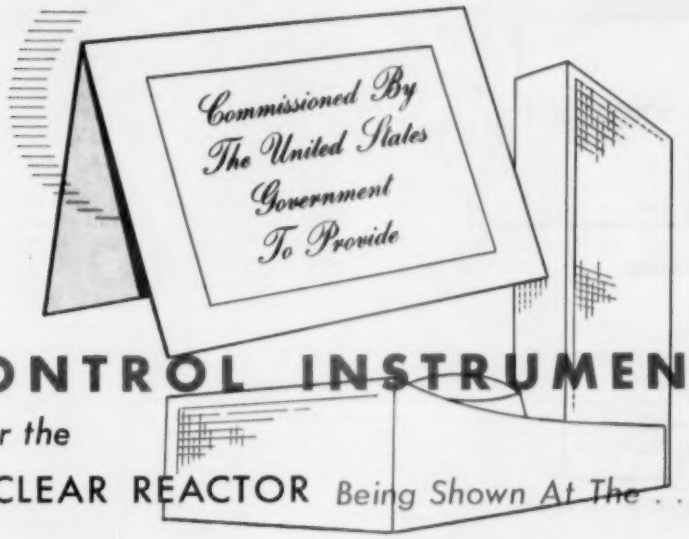

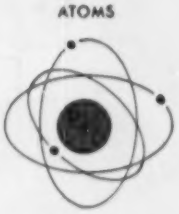

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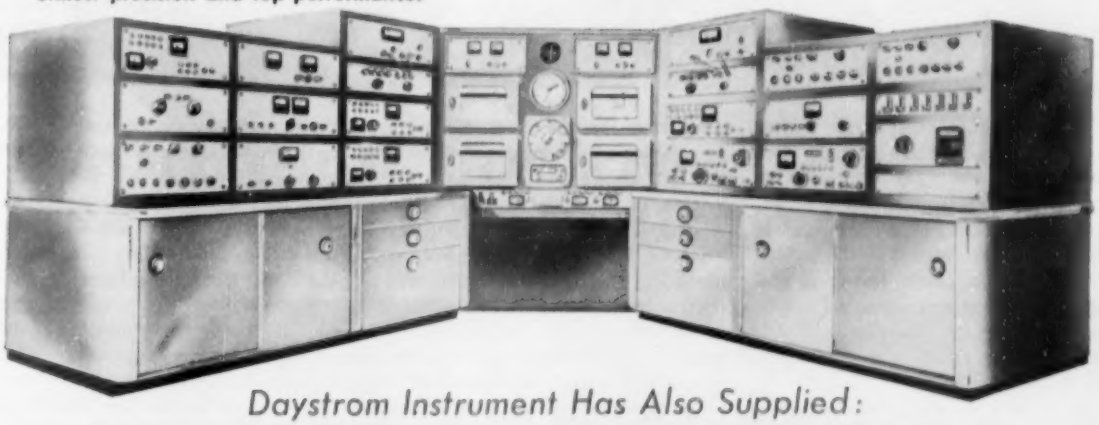

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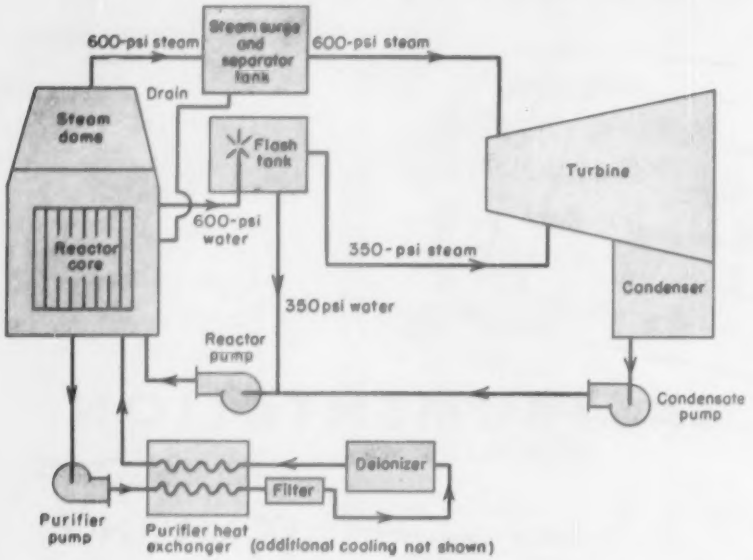


STEAM FORMED in core of boiling-water reactor drives turbine, thus depositing some radioactive corrosion products in turbine. For example described here, reactor output is 700 Mw of heat for 200 Mw electricity; other specifications are: specific operating temperature, 500° F; specific power in uranium fuel, 10 Mw of heat/ton or 10 watts of heat/gm; condenser operating temperature, 100° F; reactor steam rate 2,600,000 lb/hr; water purification rate, 70,000 lb/hr; reactor vessel water content, 140,000 lb; area of zirconium fuel cladding, 9,000 ft²; internal area of stainless-steel reactor tank, 1,500 ft²; surface area in bronze condenser, 200,000 ft²; external area of turbine casing, 2,000 ft². Flash tank shown improves performance (4)

By SAMUEL UNTERMYER
Atomic Products Division
General Electric Company
Schenectady, N. Y.

With Boiling-Water Reactors

Turbine Contamination Causes Only Small Problem

How can a turbine be serviced after operating on radioactive steam? This question frequently has been raised in regard to boiling reactors. Calculations and operating experience indicate that radioactive deposits on the turbine will be only a minor nuisance, and special operating procedures will not be required, since the radiation level during turbine overhaul will not exceed safe working tolerances.

A turbine in a reactor's primary coolant loop will be highly radioactive because of the short-lived products of neutron capture by the oxygen in the coolant. For all practical purposes, these activities will vanish after shutdown. All radioactivity present during the repair period originates from impurities in the reactor water. These radioactive impurities are entrained in the minute droplets of water carried into the turbine with the steam. Calculations for a typical boiling-water power reactor define the magnitude of the problem.

Example

For the system shown, water purity in the reactor vessel is maintained by a continuous repurification system that pumps water from the reactor, cools it to 100° F, filters out particulate matter, removes the dissolved solids, reheats the water, and returns it to the reactor. Water purification is accomplished by mechanical filtration and a resin demineralizer.

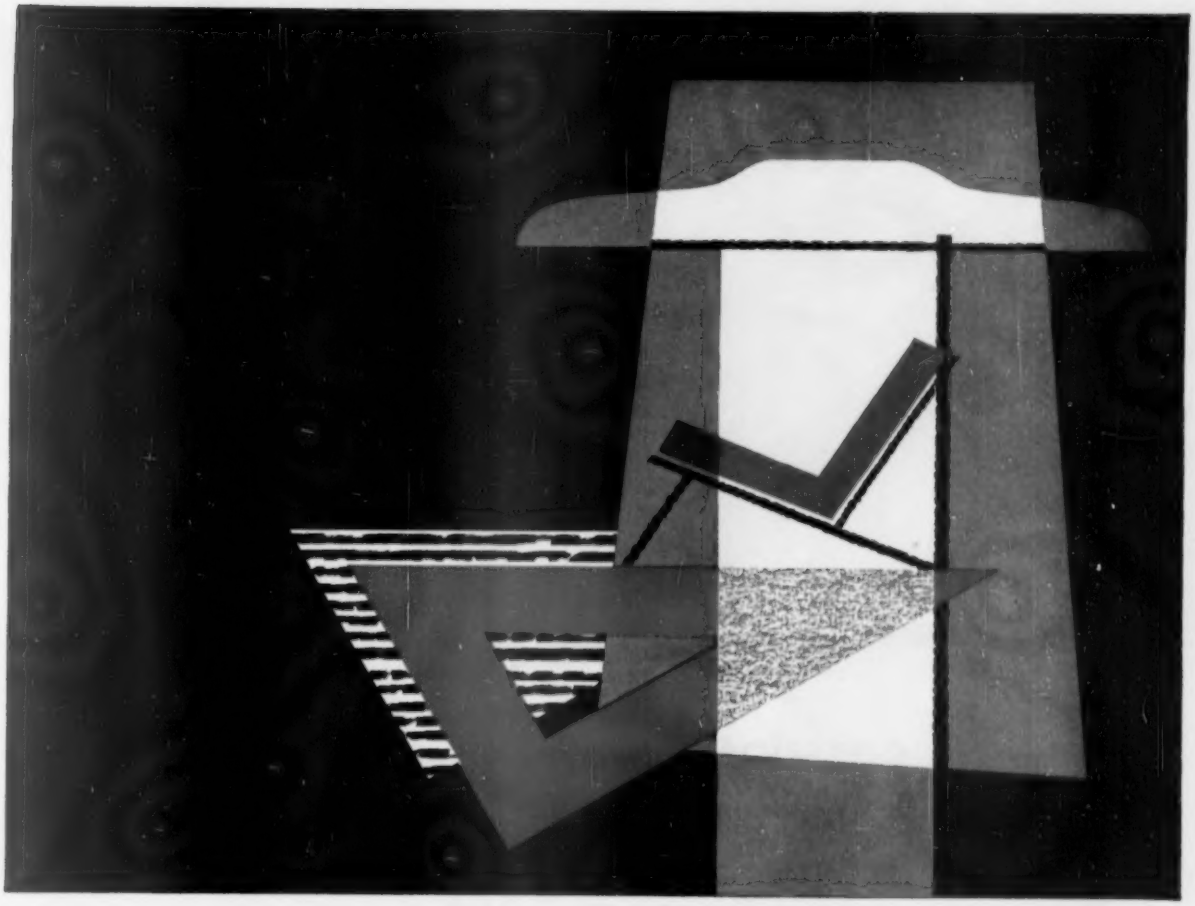
Purifier effluent. In these calculations, it is assumed that effluent from the purifier is free from impurities (*5*).

Decontamination in boiling process. Steam separators minimize the entrained water that enters the turbine with the steam. Experience in steam boiler plants with separators of this type indicates that it is possible to deliver steam to the turbine that contains <0.0001 part water by weight. Nonvolatile radioactive contaminants are transported only by water droplets, since these materials evidently are not soluble in steam. Consequently, a separation factor of at least 10^4 is expected in the boiling process (*1*). Tracer experiments confirm these estimates.

Noble fission-product gases leave the reactor with the steam, but, since these gases do not react, they pass through the turbine without adhering to the bucket and other surfaces. The noble gases do not condense either, so they are removed by the condenser air-removal system and are diluted into the atmosphere. Thus it is assumed that: F_D = concentration of radioactive impurities in steam/concentration of radioactive impurities in water $= 10^{-4}$.

Since it is evident that most of the radioactivity in the steam will pass through the turbine without being deposited on the turbine surfaces, it is assumed here that only 20% of the radioactive contaminants are so deposited. This is probably an exceedingly conservative assumption.

Corrosion of component materials. Calculation of activity requires knowledge of the corrosion rates of the principal component materials under operating conditions. Extensive corrosion tests on zirconium and stainless steel at the reactor operating temperature in a circulating system are used to estimate the corrosion rates used in these calculations (*2*). However, zirconium corrosion products form an adherent film that remains attached for long



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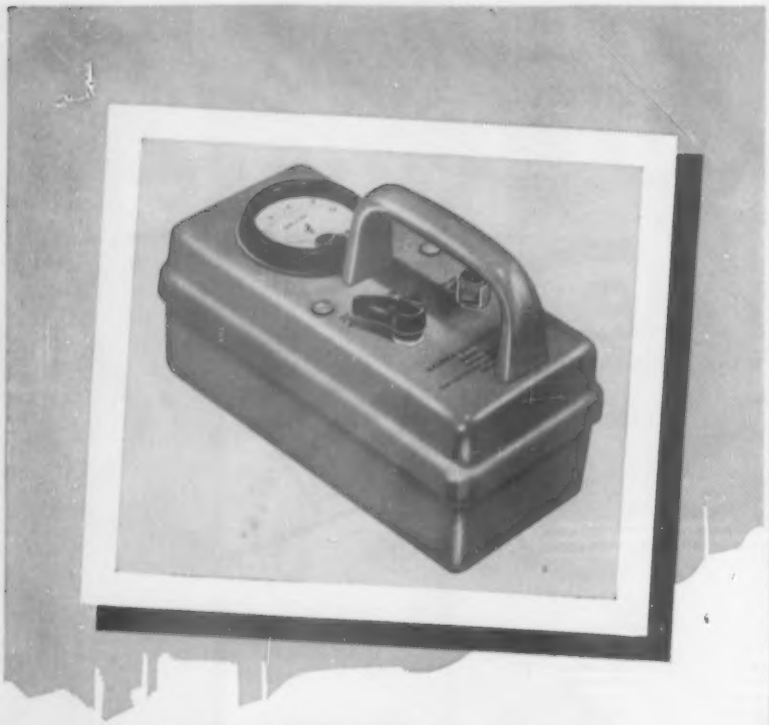

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periods. Thus, it is assumed that weight gains, as reported in these tests, indicate corrosion rate, since it is possible that some of the corrosion products finally might become detached. This is a pessimistic assumption; activity due to zirconium will be markedly lower than calculated.

Turbine corrosion. Corrosion-erosion rates in the turbine are estimated from experience with operation of these units. Experience indicates that a 200-Mw turbine will corrode or erode to the extent of about 50 lb/yr and the calculations are based on this rate.

Condenser corrosion. Condenser corrosion is assumed to be at an arbitrary rate of 0.1 mg/m²/day. In all probability, corrosion of bronze at these temperatures would be too low to measure, but there is a certain amount of erosion due to impingement of water droplets on condenser tubes. The value chosen seems reasonable in the light of experience. In any case, corrosion of the condenser is not a large contributor to turbine radioactivity, so exact information about condenser erosion rates is not necessary.

Other contaminants. Another possible source of radioactive contamination arises from leakage of cooling water into the condenser. This leakage would introduce other contaminants, such as sodium, into the reactor, and if this leakage were to reach large amounts, the radioactivity level in the turbine could be affected. The calculations include a leakage rate of 1 gal/hr into the condenser. This is a high rate of leakage, and tighter condensers should be obtainable in practice. In the special case of seawater cooling, this leakage rate would introduce serious chloride corrosion problems, so it could not be permitted for reasons other than radioactivity.

Cladding failure. Fuel element failures probably constitute the most serious source of turbine radioactivity. These failures would not occur often, yet it is expected that there will always be a small number of defective fuel elements in each fuel charge. The jackets on the elements may fail, permitting the fission products in the fuel to become dissolved in the water at some rate. The case calculated assumes that one pound of irradiated fuel suddenly becomes dissolved in the reactor water. Again, it has been assumed that the turbine must be repaired one day after this incident. These highly pessimistic assumptions lead to higher activities in the turbine

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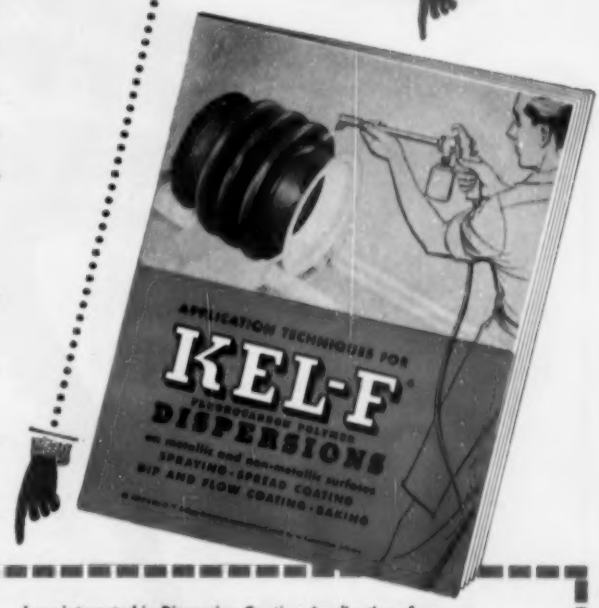

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than desirable, but this activity slowly will be reduced through a number of mechanisms. It is most improbable that a major fuel rupture would occur just before the turbine required repairs.

Turbine geometry. The turbine is considered to be a large cylinder about 60 ft long and 15 ft in diameter. It is assumed that the gamma-emitting contaminants are deposited so that they will emit radiation outward, without any interference, even though actually the bulk of the turbine serves to eliminate radiation emitted in the direction that requires traversing the turbine. Thus, the turbine was taken to be a unidirectional source 2×10^6 cm^2 in area, and the radioactivity level at the turbine was assumed as: mr/hr at turbine = Mev/sec of gammas emitted/area of turbine casing. These assumptions also are somewhat pessimistic, since a large portion of the gammas will be emitted far into the turbine structure. An assumption that the turbine is a uniform mixture of gamma-ray absorbing metal, voids, and active material might be more realistic, and this assumption would result in approximately 10% as high a radiation level.

Time of operation. The calculation considers the case in which the reactor has operated for a very long period prior to turbine repair; thus, all activities are assumed saturated. Actually, in the case of cobalt, which occurs as a trace impurity in the reactor vessel material, saturation would not be reached for about 10 years, so the radioactivity from this source would be lower than predicted until this amount of operation had been achieved.

Maintenance. It has been assumed that maintenance work will not be started on the turbine until one day after reactor shutdown. This permits various short-lived activities to decay. Since it is necessary to allow the steam system time to cool off in the thermal sense, this period of waiting will not handicap the plant operator unduly. Minor adjustments can be made on the turbine after a shorter waiting time, providing the working period is reduced to allow for the higher level of radioactivity. One day after shutdown, the principal activities are from species having greater than 8-hr half-lives.

The water repurification system can process the equivalent of the entire liquid content of the reactor vessel in about 2 hr. As previously mentioned, the significant radioactive species at the time of turbine repair will have

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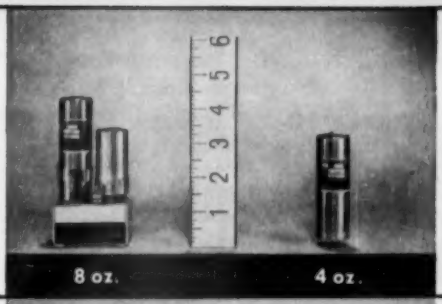

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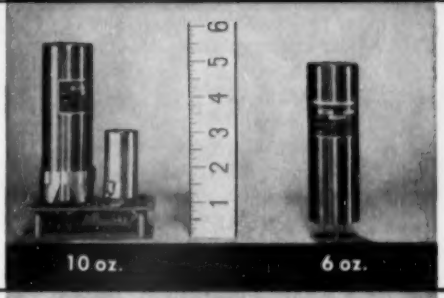

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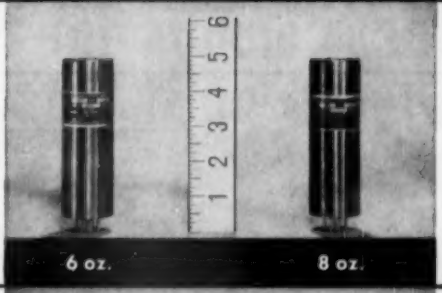

FREQUENCY STANDARD
240 to 1000 Cycles
Transistorized

Type 2007 T
± .02% at — 65° to 85°C

Type R 2007 T
± .002% at 15° to 35°C

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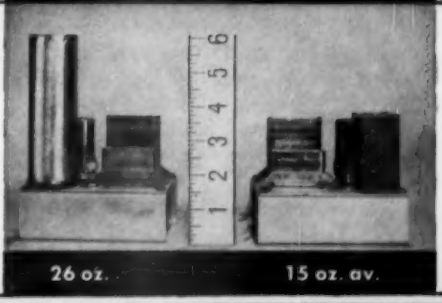

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half-lives much longer than this average repurification time.

Possibility of flushing out turbine before servicing. Experiments indicate that it is feasible to flush out most of the turbine contaminants by using special solvents. A dilute solution of periodic acid (HIO_4) generally has been found to be the most effective solvent for this purpose. Decontamination factors of 10–100 usually are obtained by these procedures; however, our calculations make no allowance for decontamination by turbine washing. For this reason, the actual radioactivities in the turbine may be very much lower than calculated.

Calculations. The following equations were used to obtain the results shown in the table.

For isotopes saturated by irradiation in reactor before corrosion, for example, materials in cladding or tank walls

$$A_S = T_D N R \phi E$$
$$= T_D N R_C R_S F_D F_T \phi \sigma E / R_p$$
$$A_C = A_S e^{-T_C/T_D}$$

In this case, activity decreases linearly with the purification rate, R_p, and activity is proportional to radioactive lifetime.

For isotopes corroding outside the reactor (such as condenser or turbine

Symbols

A_C = source of gamma activity in turbine after cooling when repairs are started

A_S = saturated source of gamma activity in the turbine

A_T = area of turbine casing (2×10^6 cm²)

E = total gamma energy per disintegration

$F = F_D F_T = 0.2 \times 10^{-4}$

F_D = concentration of radioactive impurities in steam/concentration of radioactive impurities in water = 10^{-4}

F_T = radioactivity lodging in turbine/radioactivity passing through turbine = 0.2

M = weight of water within reactor vessel = 140,000 lb

N = atoms of element/unit weight

P_C = power generated in turbine by gamma emitters at time of turbine repair

P_S = fraction of operating power produced by fission-product gammas after a shutdown period of T_S. Based on Ref. (5), P_S for 2 years continuous reactor operation is: 0.02 for T_S of 1 sec; 0.005 for 1 hr; 0.003, 6 hr; 0.002, 1 day; 0.0012, 1 week; 0.0006, 1 month; 0.0002, 6 months, 0.00015 for 1 yr.

R = rate of accumulation of solids in turbine = $R_C R_S F_T F_D / R_p$

R_C = corrosion rate, or rate of introduction of impurities

R_p = reactor water purification rate = 70,000 lb/hr

R_S = steam production rate = 2,600,000 lb/hr.

S = specific power of fuel in reactor = 10 watts of heat/gm of uranium

T_C = cooling period after reactor shutdown before repairs are started = 1 day

T_D = mean radioactive lifetime of gamma emitter

T_p = mean residence of impurities in reactor vessel = M/R_p

T_S = time after shutdown

W = weight of fuel dissolved in reactor water as result of fuel cladding failure (assumed to be 454 gm)

σ = atomic cross-section for producing gamma emitter

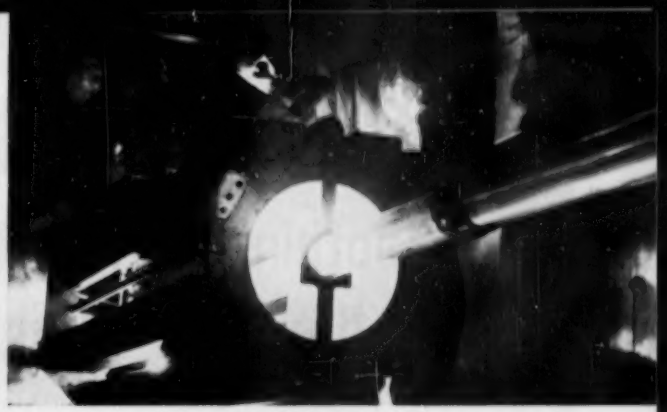
σ_E = atomic cross-section for producing 1 Mev of gamma disintegration = σE

ϕ = average effective neutron flux = 10^{11} in tank, 10^{13} in fuel cladding, 10^{13} throughout reactor

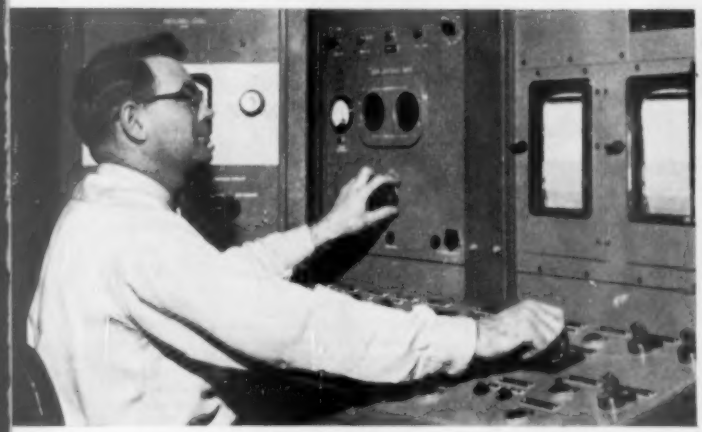
Estimates of Radiation Level in Turbine During Overhaul

	Normal operating corrosion					*Condenser leak*			
Equipment	*Reactor tank*	*Fuel cladding*	*Turbine components*		*Stellite bucket shields*	*Condenser*	*Seawater leak*	*Normal cooling water leak*	*Fuel cladding rupture*
Activated ingredient	0.07% Co	Zr	98% Fe	2% Cr	60% Co	80% Cu	1.2%	10 ppm	Fission products
Surface area, m²	150	900	—	—	—	20,000	—	—	—
Operating temp, °F	500	550	—	—	—	100 °F	—	—	550
Corrosion rate, mg/m²/day	15	30	—	—	—	1	—	—	Rapid
Total corrosion or leakage, gm/day	2.2	30	60	60	1.0	20	90,000	90,000	454 gm instantly
Ingredient corrosion or leakage, gm/day	0.0017	27	59	1.2	0.6	17	1,000	0.9	—
Active nucleus	Co^{60}	Zr^{95}	Fe^{59}	Cr^{51}	Co^{60}	Cu^{64}	Na^{24}	Na^{24}	Fission products
Mean-life, days	2,750	94	65	39	2,750	0.65	14.8	14.8	—
Atomic gamma-forming cross-section, barns	22	0.014	0.003	0.015	22	0.01	0.4	0.4	—
Gamma energy, Mev/dis	1.3	0.7	1.3	0.3	1.3	1.3	2	2	~1
Irradiation flux	10^{11}	2×10^{13}	10^{13}	10^{13}	10^{13}	10^{13}	10^{13}	10^{13}	10 w/gm
Irradiation time, hr	Sat.	Sat.	2	2	2	2	2	2	2
Mev/sec in turbine at shutdown	10^8	2×10^8	2×10^8	5×10^8	3×10^8	10^8	6×10^{10}	6×10^7	5×10^{11}
Mev/sec in turbine during repair	10^8	2×10^8	2×10^6	5×10^8	3×10^6	3×10^5	4×10^9	4×10^6	5×10^{10}
Mr/hr in turbine during repair	0.1	0.2	2×10^{-3}	5×10^{-4}	3×10^{-3}	3×10^{-4}	4	4×10^{-3}	50

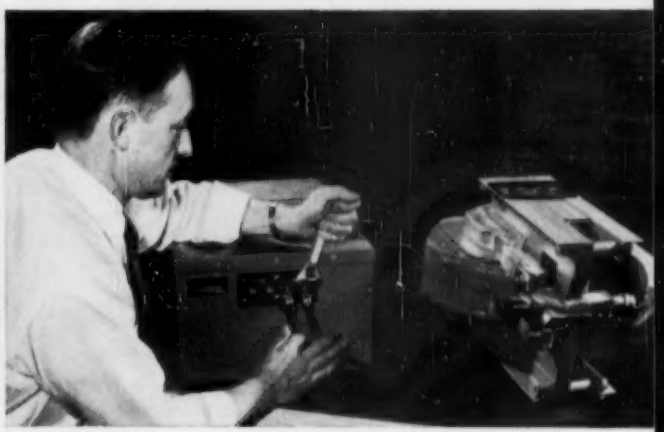
Reactor Control Rods



Reactor Core



Control Console for Reactor System



Electromagnetic Pump

Components for atomic reactor systems now available from General Electric

REACTOR CONTROLS

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- power level amplifiers
- control rods
- rod drives
- control consoles

REMOTE HANDLING EQUIPMENT

- manipulators
- optical systems
- inspection stations
- transfer dollies
- charging devices

COOLANT SYSTEM COMPONENTS

- electromagnetic pumps for sodium or molten metals
- special mechanical pumps
- stop and check valves
- freeze seals
- electromagnetic flowmeters

REACTOR SERVICE EQUIPMENT

- refueling, servicing, and maintenance equipment
- storage equipment
- fuel element record system

These components, now available from General Electric, are used in atomic reactor systems by utility, industrial, research, and educational organizations. General Electric also designs and manufactures complete nuclear reactor systems (less fissionable material). The use of the reactors will be governed by the Atomic Energy Act of 1954.

FOR SPECIFIC INFORMATION on any of these components for atomic reactor systems, contact your General Electric Apparatus Sales Office or write to: General Electric Company, Section 224-7, Schenectady 5, N.Y. Send coupon below for new bulletin on G-E Components and Services for Nuclear Reactor Systems.

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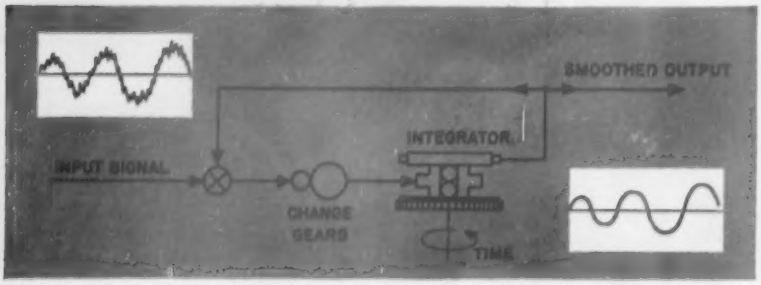
Smoothing Signal Noise with the DBR* Integrator

Confronted with the well-known problem of random fluctuations called "noise," Ford engineers have employed the earliest and best-known Ford component – the disk integrator. Used in Ford analogue computers, the disk integrator smoothes random fluctuations due to extraneous influences and obtains an average of the received signal. Thus, a device originally designed by Ford for integration is successfully used as a mechanical counterpart of the RC Filter.



The Ford circuit operates on the premise that the older the data the less important it is. Therefore, data smoothed must be weighted in proportion to its age, so that the weight assigned to it decreases exponentially with time. The output of the circuit then represents the summation of this weighted data and tends to ignore random noises of short time duration.

As shown in the drawing, the incoming signal (with noise superimposed) is the input to the differential. As long as the integrator output (the roller) rotates at the *same rate* as the incoming signal, the differential output (error signal) is stationary and the integrator carriage remains stationary. But any change in the incoming signal produces changes in the *error signal* which tends to displace the integrator carriage and thus restore the system to equilibrium.

This reaction, however, is not instantaneous. It occurs after a certain time-lag which may be adjusted by the gear ratio. If the signal is of brief, random nature, the time-lag of the integrator will prevent its acting on the system. On the other hand, a permanent change in the signal will displace the carriage and change the output of the system.

This use of the Ford disk integrator as a noise smoother exemplifies the flexibility and adaptability of Ford components and ideas.

*Disk, Balls and Roller Integrator

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materials) and for isotopes entering the reactor through leakage

$$A_S = T_p N R \phi E$$
$$= M N R_C R_S F_D F_T \phi \sigma E / R_p^2$$
$$A_C = A_S e^{-T_C/T_D}$$

In this case, activity decreases quadratically with the purification rate and is independent of radioactive lifetime.

For a fuel-element jacket rupture that introduces fission products into the reactor water

$$P_C = P_S W S R_S F_D F_T / R_p$$

As in the case of isotopes saturated in the reactor, activity decreases linearly with R_p. P_C in watts may be converted to A_C in Mev/sec by multiplying by 6×10^{12}.

For the assumptions used in these calculations, mr/hr at turbine = $A_C / 500 A_T$, where A_C is in Mev/sec and A_T is in cm²; thus mr/hr = $A_C \times 10^{-9}$.

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4. S. Untermyer, NUCLEONICS, **13**, No. 7, 34 (1955)
5. M. Sivets, C. H. Scheibelhut. Application of mixed bed ion exchange resins to water purification in nuclear reactors, *Ind. Eng. Chem.* **47**, 1020 (1955)

REACTOR FACTS

British partly follow NBS recommendations for waste disposal. High-activity solid wastes, after incineration concentration, are put in polyethylene-coated standard 55-gal. steel drums, embedded in gravel, surrounded by 4–6-in.-thick concrete and by an outer steel shell, and then dumped by the Atomic Energy Authority in 2,000-fathom-deep water (U. S. National Bureau of Standards Handbook 58 recommends >1,000 fathoms). Although Handbook 58 considers pipeline disposal as undesirable, some liquid wastes are discharged into the sea by pipeline. Controlled land burial sometimes is used for solids.

Radiation damage may force use of one-compartment HTR. Radiation damage to the 32-in.-i.d. Zircaloy-2 tank separating the core from the blanket-reflector of Oak Ridge National Laboratory's Homogeneous Test Reactor may necessitate using a one-compartment system (NU, June '55, p. 41). It has been planned to develop HRT in three steps as far as the blanket is concerned: first it will use heavy water, then thorium, then depleted uranium. Fuel would be U^{235} at first, later U^{233}.

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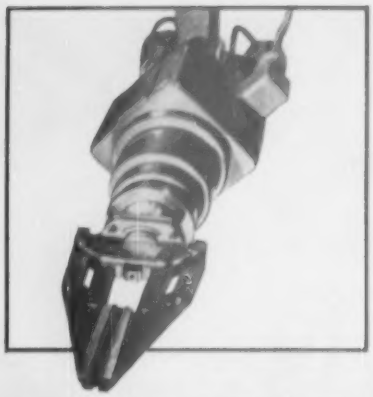

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TECHNICAL ADVANCES

Bevatron Produces the New Particles The 6.2-Bev proton synchrotron at the University of California Radiation Laboratory has operated stably for several months now, and research results are beginning to emerge. The huge machine provides a controllable source of almost all the strange new particles observed with certainty in the cosmic radiation; thus far τ^+, τ^-, $K_{\mu 2}^+$, $K_{\mu 3}^+$, $K_{\pi 2}^+$, $K_{\pi 3}^+$, K^-, θ^o, Λ^o, Σ^-, and hyperfragments have been identified among the products of Bevatron reactions. Pions are available in an external 5-Bev beam; there is also a less-pure K-meson beam.

The full armory of modern high-energy physics is used to study the new particles: nuclear-track emulsions in large blocks, high-pressure cloud chambers, liquid-hydrogen bubble chambers, and scintillation telescopes.

Some results: mass of $K_{\mu 2}^+$, 957 m_e, of K^-, 965 m_e; interaction cross section of K^- appears geometrical; π^-, p collision cross sections in millibarns: at 1.9 Bev, 35 ± 2; at 3.2, 26 ± 3; at 4.5, 24 ± 2.

Uranium-Glass Neutron Detector Uranium fission in fluorescent-U glass has been used to detect slow neutrons with 1% efficiency while discriminating against gammas. The detector is a 0.6-mm-thick slip of the glass, polished, and bound to a Lucite light pipe with a viscous mixture of matching index of refraction. Light pulses are detected with a photomultiplier. U alpha particles and background gammas can be biased out without losing more than half the fission pulses.

The fluorescent glass is compounded in molar proportions $2\ SiO_2$:$\frac{1}{2}\ Na_2O$:-$\frac{1}{2}\ K_2O$ with 15% by weight of uranyl nitrate hexahydrate. The pure ingredients are melted in Al_2O_3 dishes at 1,280° C for 6–8 hr, then cooled slowly. The resulting glass is transparent and strongly green fluorescent, absorption is a maximum in the ultraviolet, decreases toward the visible.

This work, by Kovacevic and Kostic, is published in *Bulletin of the Institute of Nuclear Sciences "Boris Kidrich"* No. 79, 49 (1950).

N^{15}-Enriched $Th(NO_3)_4$ for Th Reactors? A practical process for the enrichment of nitrogen to 95% N^{15} (natural abundance is 0.38%) may find application in preparing this low-cross-section isotope for breeder reactors.

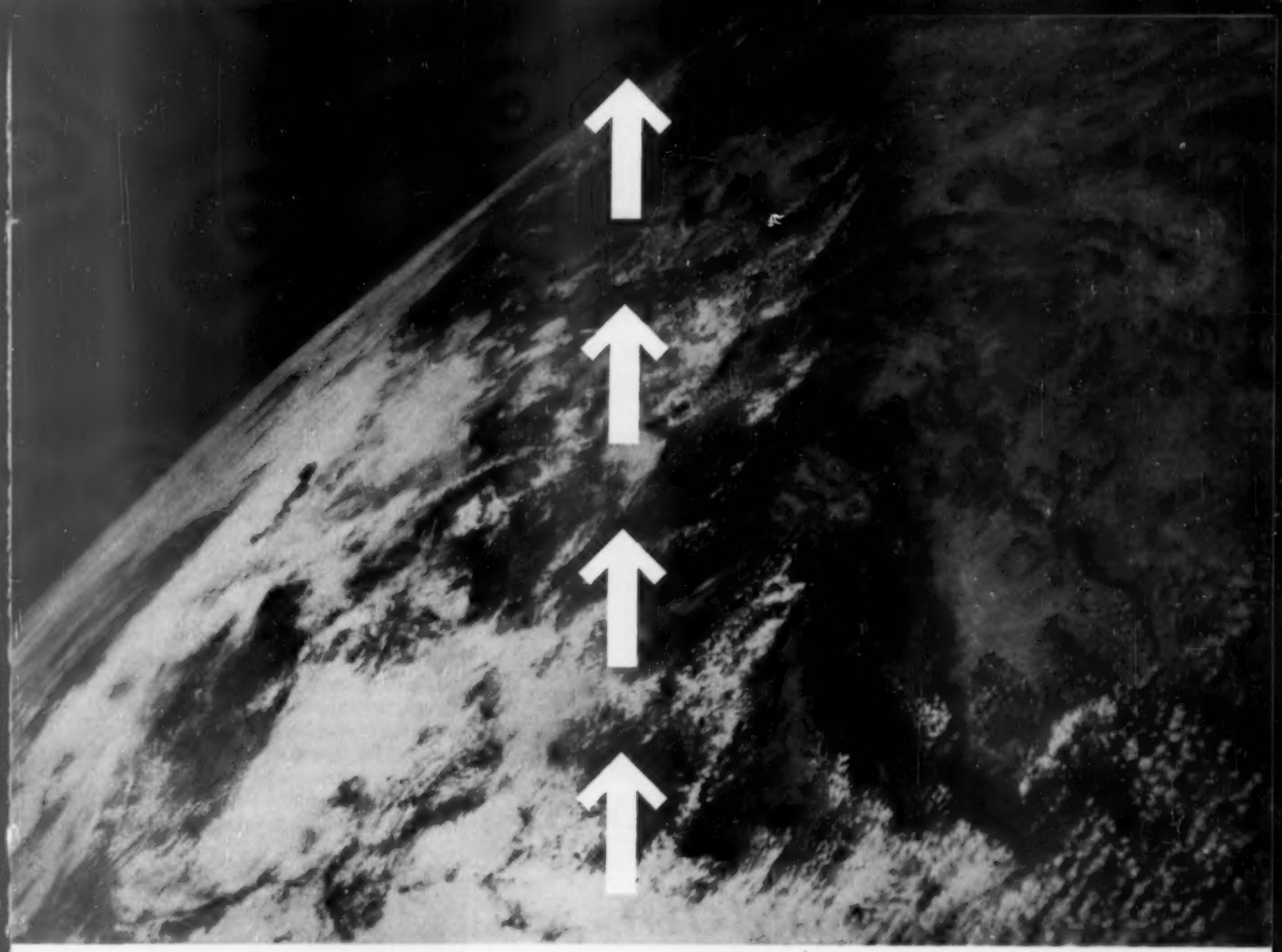
The problem N^{15} solves is this: aqueous-solution thorium breeder reactors (NU, June '54, p. 12) require a soluble low-absorption-cross-section thorium compound. Thorium nitrate, $Th(NO_3)_4$, is one of the few compounds satisfying the solubility requirements, but its neutron-absorption cross section is too high because of the 1.4-barn absorption cross section of the abundant (99.62%) N^{14} isotope. Enriching nitrogen to 95% N^{15} ($\sigma = 0.08$ mb) would eliminate this difficulty.

The new process takes advantage of a small enrichment (enrichment per stage, α, >1.05) of N^{15} in the liquid phase of the equilibrium: NO (gas) $\leftrightarrow$ HNO_3 (liquid). Nitric acid drips down the length of an exchange column and is converted to NO and NO_2 by reaction with SO_2, $10M$ H_2SO_4 being formed in the process. These gaseous oxides of nitrogen rise back through the column and eventually are reconverted to HNO_3 by passing through water. On the trip up the column exchange reactions take place and result in the HNO_3 at the bottom becoming enriched in N^{15}. For a 1.5-meter column, a 1.5-cm³/cm²/min flow of $10M$ HNO_3 resulted in an over-all equilibrium separation of 7 after 12 hr, report Columbia U. researchers T. I. Taylor and W. Spindel.

Optimum conditions are still being sought, but it already appears that the process can yield reactor-grade nitrogen for about $500/lb. The favorable value of enrichment factor (plant size goes as $(\alpha - 1)^{-2}$), the fact that HNO_3 is recovered and need only be "borrowed," and the fact that a useful chemical, H_2SO_4, is a by-product help make the scheme economic.

The 5 tons of N^{15} required for a 100-Mw Th breeder reactor could be supplied in 200 days by a 50-lb/day plant that would cost something like $10–30-million and produce 1,250 tons of H_2SO_4 per day as a by-product.

One worry: how will radiation damage affect $Th(NO_3)_4$?



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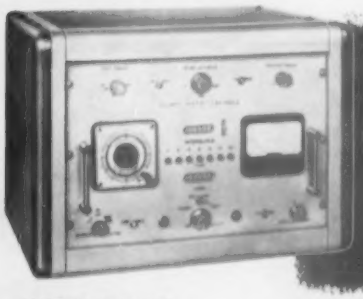

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BOOKS

Atomic and Nuclear Physics

By R. S. SHANKLAND (The Macmillan Co., New York, 1955, xv + 529 pages, $7.75). Reviewed by LEON M. LEDERMAN, Department of Physics, Columbia University, New York, N. Y.

This book is intended as an introductory textbook in modern physics for seniors and first-year graduate students. In many ways the treatment is most suited for more mature non-physicists: chemists, biologists, and engineers. It is no longer necessary to emphasize the intimate relation between modern physics and engineering as exemplified by such recent engineering revolutions as electronics, nuclear energy, and transistors. As a detailed descriptive survey of the foundations and frontiers of modern physics, this textbook should prove invaluable to the young engineer, who will be wise to keep his eyes opened to the advances in this basic domain.

To the engineer and to the science student whose studies depend increasingly on the knowledge of the structure of molecules, atoms and nuclei, the level and presentation of material is ideal. Subjects are generally introduced historically with references to the original literature. The reader is then led to the most modern interpretation of the subject, again with ample references to the very recent literature. For example, the section on neutrons begins with a description of Chadwick's experiment, continues on to describe the experiments which establish the magnetic moment, lifetime and diffraction of neutrons, and ends with a brief discussion of the neutron-electron interaction. The emphasis is on the fundamental phenomena, theoretical sections are descriptive with a minimum of mathematical detail. Generally the relevant theory is presented in the form of a basic equation, supplemented by explanatory discussion of the underlying ideas and experimental implications.

In addition to the conventional topics in atomic and nuclear physics (kinetic theory, the electron, atomic structure and spectra, molecular structure and spectra, X-rays, nuclear structure, natural radioactivity, nuclear transformations), there is a very clear survey of solid state, a detailed chapter on nuclear energy sources, which includes thermonuclear and fission reactions, and a discussion

of the fundamentals of reactor technology. Two concluding chapters outline the frontiers in high energy and particle physics. Many diagrams, photographs, and tables supplement the lucid expos tion of material.

For physics students, the text tends to be too qualitative and would have to be shored up by additional mathematical detail and by problems (there are none in the text). As is, it could serve to instill in the student a burning desire to go more deeply into the subject.

BOOKS RECEIVED

Materials for Nuclear Power Reactors, by Henry H. Hausner and Stanley B. Roboff (Reinhold Publishing Corp., New York, 1955, 224 pages, $3.50). (*To be reviewed.*)

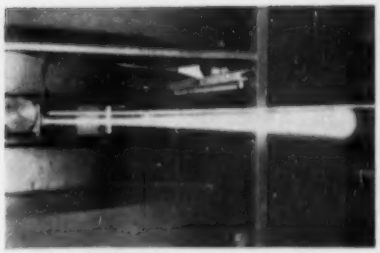
Modern Physics, by John C. Slater (McGraw-Hill Publishing Co., Inc., 1955, xi + 322 pages, $5.50). Descriptive rather than mathematical, this book outlines the logic behind the development of theoretical physics since 1900.

Elements of Physics, 2nd edit., by George Shortley and Dudley Williams (Prentice-Hall, Inc., New York, 1955, xiv + 880 pages, $10.60). Written for science and engineering students, this new edition treats several new topics in addition to those of the 1953 edition: relative velocities, dynamical systems, fluid viscosity, surface phenomena in liquids, Gauss' law in electrostatics, thermionic vacuum tubes, transistors, and newly discovered particles.

Electronic Circuits, by Thomas L. Martin, Jr. (Prentice-Hall, Inc., New York, 1955, xix + 707 pages, $12.00). Following an introductory discussion of equivalent circuits and the elements of electric circuit theory, this book mainly concerns itself with circuits requiring continuous operation of an electronic component (*Class A Circuits*) and circuits requiring discontinuous operation (*Operation in the Switching Mode*). The analytical approach provides a basis for circuit formulation.

Manganese—Metallurgy of the Rarer Metals No. 3, by A. H. Sully (Academic Press, Inc., New York, 1955, xiv + 305 pages, $6.50). With the recent commercial availability of high-purity manganese, this book is timely as a source of the metal's current technology. Topics covered are the occur-

Below is shown the interior of one of NSEC's modern radiochemical laboratories. Photograph (right) was taken of the cyclotron at the Sara Mellon Scaife Radiation Laboratory at the University of Pittsburgh.



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General Principles of Geology, by J. F. Kirkaldy (Philosophical Library, Inc., New York, 1955, 327 pages, $6.00). While not attempting to serve as a data reference, this book provides a basis for understanding such information, which can be found in the works listed.

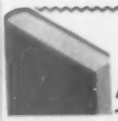
Gas Dynamics of Cosmic Clouds (Interscience Publishers, Inc., New York, 1955, xii + 247 pages, $5.75). This book reports a symposium held at Cambridge, England, July 1953, under the auspices of the International Astronomical Union and the International Union of Theoretical and Applied Mechanics. Some of the discussions are also included.

Progress in Nuclear Energy Series. This new series will cover: physics and mathematics, reactors, nuclear chemical engineering, technology and metallurgy, biology economics and power resources. The first volume in each subject, published as soon as feasible after the Geneva conference on nuclear energy, will consist mainly of papers presented at the conference. *Pergamon Press Ltd., London (distribution in Western Hemisphere: McGraw Hill Book Co., Inc., New York).*

General Physics, 2nd edit., by Oswald Blackwood and William Kelly (John Wiley & Sons, Inc., New York, 1955, x + 704 pages, $6.75). An elementary introduction to physics, this book uses mathematics below the level of calculus and draws upon homely phenomena to illustrate physical principles. Content is increased and discussion of nuclear material is expanded.

ALSO OF NOTE

A Glossary of Terms in Nuclear Science and Technology. Under the sponsorship of the National Research Council Conference on Glossary of Terms in Nuclear Science and Technology, sections have been published covering terms in physics, reactor theory, reactor engineering, chemistry, chemical engineering, biophysics, radiobiology, instrumentation, isotopes separation, and metallurgy. As a result of comments on these sections, the present revised glossary is available as a proposed American Standard. *The American Society of Mechanical Engineers, 29 West 39th St., New York 18, N. Y., $5.00.*



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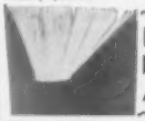

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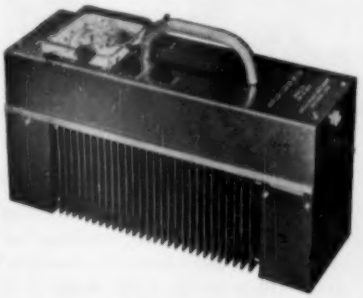


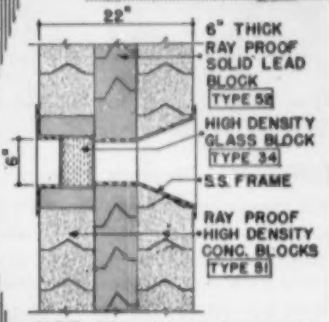
Meter is calibrated in mercury concentrations for quick indication. The toxic limit is a full-scale reading on the high sensitivity scale of Model 23, illustrated. Wt.: 7 lbs.; size 13" x 8½" x 4½". Three models for varying ranges.

Write for bibliography on the mercury vapor hazard, and literature on Kruger Mercury Vapor Meters.

HAROLD KRUGER INSTRUMENTS

BOX 164 • SAN GABRIEL, CALIF.

radiation shielding by **RAY PROOF**


22"
6" THICK RAY PROOF SOLID LEAD BLOCK TYPE 58
HIGH DENSITY GLASS BLOCK TYPE 34
6"
S.S. FRAME
RAY PROOF HIGH DENSITY CONC. BLOCKS TYPE 81

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. . . . . data recording and in various combinations to meet your requirements.

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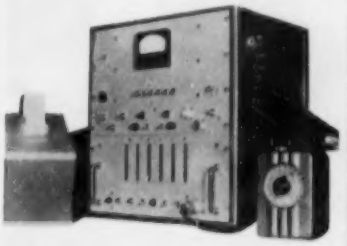

The Devtron Model 130-2, Automatic Digital Pulse Analyzer

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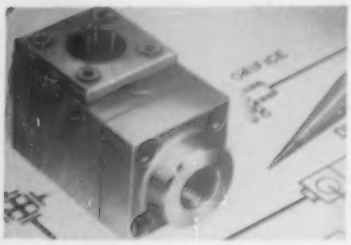
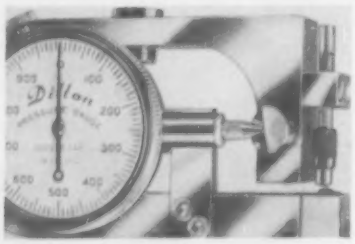
PRODUCTS AND MATERIALS



Differential-Pressure Pickup

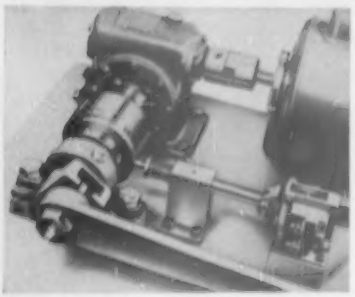
For measuring differential pressures in presence of up to 2,000 psi, Dynisco units use an unbonded strain-gage sensing element. Pressure ranges are from 0 to 10, 25, 50, . . . 1,000 psi. Accuracy is 0.5% of full scale. Minimum full-scale outputs are 20, 40, or 50 mv.—Dynamic Instrument Co., 28 Carleton, Cambridge, Mass.



Pressure Gage + Switch

Control action at any preset pressure on gage results from this combination of pressure gage and microswitch. Any of 10 gage capacities, from 0–10 to 0–10,000 psi, can be used. Gage accuracy is 1%. Switch carries 5 amp a-c or 2 amp of 30 v d-c.—W. C. Dillon & Co., Box 3008, Van Nuys, Calif.

PIPING COMPONENTS



Controlled-Volume Pumps

Two different approaches to pumping controlled volumes are taken by these metering pumps.

• Single revolution, clutch-operated Uni-feeders (above) go through one cycle each time a solenoid or air cylinder is energized. Capacity is preadjusted to provide exact slug of fluid. Repetition rate is 1–72 per min, controlled by time cycle, flow, *p*H, or other factors. Capacities are 9×10^{-5} to 27 gal/min.—Philadelphia Pump and Machinery Co., 1513 Race St., Philadelphia, Pa.

• Fluid-flow control at pressures from 7,500–50,000 psi are offered by new pumps, with capacities from 12.5–94 gal/hr. Complete scavenging of liquid-end displacement chamber assures high volumetric efficiency, regardless of plunger stroke length. Pump is built of 300 series s. s. or Ni-Cr-Mo steel.—Milton Roy Co., 1300 E. Mermaid Ln., Philadelphia 18, Pa.

Unique Check Valve

Technocheck uses valve body, rather than valve seat, to allow straight-line flow when valve is open. When flow reverses, valve elements expand against wall to seal. Range of materials may be used in valve construction. Special valves handle 400 psi pressure and 500° F temperature.—Techno Corp., 16 West 5 St., Erie, Pa.

Products Index

Piping Components.....68

Electronic Instruments and Apparatus.....68

Radiation Detectors and Accessories.....72

Industry Notes.....73

Literature Available 74

ELECTRONIC INSTRUMENTS AND APPARATUS

Analog-Digital Converter

Besides use on a computer, applications for ADC-1A converter include use as high-speed electromechanical counter and totalizer, digital clock, telemetering, conversion of shaft position to analog voltages, and *vice versa*. Combined with potentiometric system, converter records values from many transducer types into many types of outputs. Unit is $1\frac{3}{4} \times 2\frac{3}{4}$ in. Output is 13 binary numbers, but modifications make number of digits practically unlimited.—Norden-Ketay Corp., 99 Park Ave., New York 16, N. Y.

Voltage Amplifiers

Two amplifiers, for thermocouple and similar uses have been announced. Different principles are used.

• Portable selective range d-c proportional amplifier, model 2HLA-4, uses a second-harmonic magnetic converter as the input modulator. Plug-in units provide ranges from 0.1–100 mv, with gains varying from 10^5–100. Linear response is achieved from d-c to 20 cycle/sec. Unit withstands inputs up to 1,500 × full scale.—Doelcam, Soldiers Field Rd., Boston 35, Mass.

• Using a high-impedance, null-balance system, model T2C takes d-c signals and converts them to a 0.0–0.500-volt 60∼ signal. Converter uses no batteries, slide wires, solenoids or motors. Minimum span is 2 mv; spans as low as 0.4 mv can be handled. Range is changed by changing cards; thus temperature ranges from −50–3,000° F are covered.—Swartwout Co., 18511 Euclid Ave., Cleveland 12, Ohio.

L&N Precision Stabilized Power Supplies guard instrument accuracy against line voltage fluctuations

• Leeds & Northrup has developed two types of power supplies to meet the precision requirements of our own instruments such as the Recording Spectrometer, the Electro-Chemograph® and the Infrared Gas Analyzer. These power supplies have been so successful that we are now making them available for general use.

For Multiplier Phototubes and Similar High Voltage Applications

Two Independent Output Voltage Sources — Ranges
(1) 500 to 1310 volts d-c across 1 megohm load. Continuously adjustable with coarse and fine dials. (*1; see fig.*)
(2) 480 to 790 volts d-c across 1 megohm load. Continuously adjustable with 12-position coarse dial only. (*2; see fig.*)

Line Voltage Tolerance—0.01% d-c output change for a change in a-c line voltage from 100 to 125 volts.

Drift—Not more than 0.01% for a period of 8 hours or more, after a 20-minute warmup.

Ripple—Considerably less than 30 millivolts rms.

Time Delay Relay Circuit—30 second time delay allows tube heaters to come to proper operating temperature before high voltage is applied. (*3; see fig.*)

Size—19″ x 10½″ x 10″, for relay rack mounting.

Catalog Number—101038

Price—$715.00 F.O.B. Phila.; subject to change without notice.

For General Purpose Laboratory Applications

Output Voltage Range—105 to 125 volts d-c, continuously adjustable.

Current Range—0–200 ma at 105 volts.

Stability—0.05% d-c output change for a change in a-c line voltage from 105 to 125 volts.

Drift—No greater than 0.05% in 24 hours.

Load Current Regulation—At 105 volts output, load change from 0 to 200 ma produces a 0.05% change in output voltage.

Ripple—Less than 5 millivolts rms.

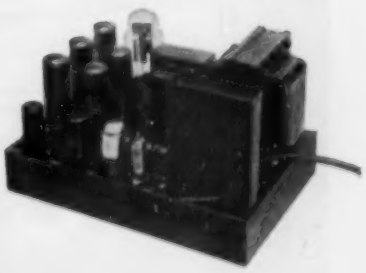
Size—9 1/16″ x 13 5/16″ x 9 7/16″, with metal case.

Catalog Number—101-2-0-2

Price—$276.00 F.O.B. Phila., subject to change without notice.

Catalog Number—101-2-0-1, same as above except includes chassis only without metal case and has a constant voltage output of 105 volts.

Price—$203.00 F.O.B. Phila., subject to change without notice.



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Metal-Walled—Resist Shock

Except for a glass bead insulator, Lelab counter tubes are constructed entirely of metal. The metal cylinder is used both as the envelope and cathode of the tube—providing it with strength, resistance to shock and simplicity of design.

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18-Range a-c Standard

Guaranteed without time limit to maintain 0.1% accuracy, DYL transformer-coupled electrodynamometer has 13 full scale settings from 5 ma–10 amp, and 7 settings from 5–500 volts. One model is for 50–500 cycle current, another for 50–70. Vernier scale is 12-in. long, has anti-parallax mirror.—Sensitive Research Instrument Corp., 9–11 Elm Ave., Mt. Vernon, N. Y.

24-Galvanometer Package

For simultaneous display of 24 separate electrical signals, model 20 visual monitor combines 24 moving-spot galvanometers in one $8\frac{1}{2} \times 8\frac{1}{2} \times 6$-in. package. Screen is 3×4 in. Full-scale deflection is 0.24 ma. Spots can be photographed or viewed under high incident light.—Century Geophysical Corp., 1333 N. Utica, Tulsa, Okla.

Binary Multi-Resistor

Values from 0–131,070 ohm in 2-ohm increments are realized by connecting resistors in sealed metal unit, BMR-105. Error is 0.01% above 3,000 ohms, and 0.0015% at maximum setting. Temperature coefficient is within 5 ppm/° C at 20° C.—Julie Research Laboratories, 341 E. 149 St., Bronx 51, N. Y.

•

Tester for n or p conductivity. Sample contacted by probes of JR1 tester reveals either n or p type conductivity by direction of galvanometer-pointer swing.—Baird Associ-

ates, Inc., Dept. SN, 33 University Rd., Cambridge 38, Mass.

Portable potentiometer. Readable to 0.025 mv, this portable 10-lb instrument has a 40-in. scale. Models are available with built-in run-up box and calibrated rheostat for line-resistance compensation.—Wheelco Instruments Division, Barber-Colman Co., Rockford, Ill.

Hot-wire time-delay relays. Time delays from 0.1–5 sec, with recovery after only a few seconds cooling, are provided by series H thermal relays. Energizing voltages range from 6.3–28 v, interchangeably d-c or any frequency a-c. Contacts are rated 3 amp, 115 v a-c.—G-V Controls Inc., 28 Hollywood Plaza, East Orange, N. J.

Leakage-current meter. Claimed comparable to mirror-type galvanometers, model 63 measures currents from 0.001–1,000 μa with 4% accuracy. With voltage source, meter becomes a megohmmeter; and with multiplier resistor, meter becomes high-resistance voltmeter.—The Hewson Co., 443 Broad St., Newark 2, N. J.

Portable potentiometer. Accuracy of 0.5% is attribute of 7-range indicator covering 0.25–25 mv. Balance is indicated by light-beam galvanometer, and no standard cell is needed. Four input channels permit multiple scanning.—Beckman & Whitley, Inc., 974 E. San Carlos Ave., San Carlos, Calif.

Two-pole mercury relays. Alumina mercury-holding cups are features of hermetically sealed 2-pole, single throw relays. Ratings are 35 a at 115 v a-c for EM-4; and 60 a for HD-4. Ratings for d-c are 12 a at 120 v, 7 a at 240 v for both models.—Ebert Electronics Corp., 212–260 Jamaica Ave., Queens Village 28, N. Y.

Non-rigid Teflon tubing. Teflon tubing for class H service is flexible from −90–260° C. Inside diameters are 0.014–0.112 in., with other sizes on special order.—Hitemp Wires, Inc., 26 Windsor Ave., Mineola, N. Y.

Automatic capacitance indicator. With counter readout for capacitance and dissipation, 601-A will measure from 100 μμf–1.00 μf, with 6% dissipation factors. Instrument can be modified for digital readout.—G. M.

"... a minimum rise time of 0.08 Microseconds..."

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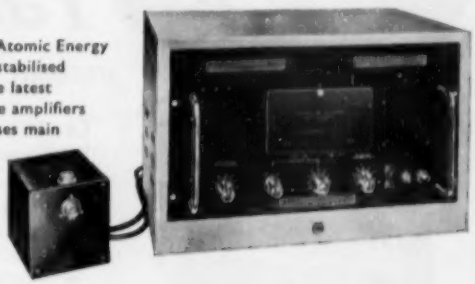
As every schoolmaster knows, pupils are from time to time capable of the most learned dissertations on subjects completely outside the matter in hand. Not, it should be added, that these often concern such specialised subjects as Linear Amplifiers. To be put fully in the picture on this it is necessary to talk to EKCO, who have all the relevant details at their finger-tips.

LINEAR AMPLIFIER TYPE N568

Developed in conjunction with the Atomic Energy Research Establishment, this highly stabilised wide-band amplifier incorporates the latest advances in the design of linear pulse amplifiers for use in nuclear physics. It comprises main amplifier; H.F. head amplifier; and cathode-follower head amplifier for use with particle counters working in the proportional region. A maximum overall voltage gain of 1,000,000 is provided and gain stability is of the order of 0.1%.



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Nominal Properties of Hevimet

Mechanical Properties:

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Hardness (Rockwell "C")	20—30
Modulus of Elasticity (p.s.i.)	50×10^6
Modulus of Rupture (p.s.i.)	200,000
Yield Strength (0.2% offset) (p.s.i.)	75,000
Elongation (% in 2 inches)	2% Min.
Proportional Elastic Limit (p.s.i.)	27,000

Thermal Properties:

Coefficient of Thermal Expansion (in./in./°C) (20°-400°C)	5.6×10^{-6}

Electrical Properties:

Electrical Conductivity	15.4% I.A.C.S.
Magnetic Permeability	non-magnetic

Shielding Properties:

X-Ray Absorption @ 2,000,000 volts	1.4 x lead
Half-Value Layer for Co^{60} (inches) (narrow beam)	0.330
(broad beam)	0.344

Carboloy® Hevimet makes a more effective gamma- or X-ray shield – with less bulk – than lead. This tungsten-nickel-copper alloy is an ideal material for shielding applications where size and weight are critical.

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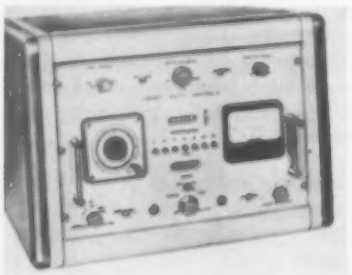
Attura, Industrial Control Co., Wyandanch, New York

Heavy-duty-work solenoid. Single-coil push type solenoid, model 9300, has 1.85-lb pull at start of 0.1-in. stroke. Rating of solenoid that operates $2–3 \times 10^4$ times daily in one application is 18–30 v d-c, size is about 2×1 in.—Carruthers & Fernandez, Inc., 1501 Colorado Ave., Santa Monica, Calif.

RADIATION DETECTORS AND ACCESSORIES

Scintillating Goggles

Gamma-sensitive scintillator combined with reference luminosity segments makes this light-tight goggle a radiation detector. Nine calibration segments allow monitoring from <0.3–50 r/hr. Focusing and anti-fogging devices are built-in.—Auergesellschaft A. G., Berlin N 65, Friedrich-Krause-Uper 24, Germany.



Combination Scaler-Ratemeter

Model B-1800R has a linear amplifier and discriminator, preset time or count controls, two timers, regulated high voltage from 700–2,000 v, and Higginbotham scale of 128; plus a count-rate meter with six ranges from 5–10^4 cps and a choice of five %-error settings.—NRD Instrument Co., 6425 Etzel St., St. Louis 14, Mo.

1-Microsecond Scaler

Only 1% coincidence loss for rates up to 10^6 cpm results from 1-μs resolving time in new decade counters. Input trigger voltage is 75–150 v negative, output is same; making counters suitable for cascade operation. Read-

out is 10 neon lamps.—Tracerlab, Inc., 130 High St., Boston 10, Mass.

Gamma Spectrometer

Complete system for spectrometry in model 513 includes NaI well crystal, photomultiplier, linear amplifier, pulse-height analyzer, preset time scaler, and high-voltage supply. Additional counters can be substituted for well crystal. High-voltage supply has 0.02% drift/day, output is within 0.01% despite 100–130 v line variations.—Atomic Instrument Co., 84 Massachusetts Ave., Cambridge 39, Mass.

•

Transistorized flip-flop. Encapsulated plug-in binary element, type 200C5, is $1\frac{5}{8} \times 1\frac{5}{16}$ in., and has standard 7-pin base. Power and space needed are claimed $\frac{1}{3}$rd less than tube flip-flops.—Sprague Electric Co., 259 Marshall St., North Adams, Mass.

Digital delay generator. Crystal-controlled digital delay generator provides pulses delayed in time with respect to internally generated reference pulse, at any repetition rate. Accuracy is >1 ppm.—Kaiser Metal Products, Inc., Bristol, Pa.

Events-per-time meter. Five digit meter registers 10^5 cps with 1 count accuracy using crystal-controlled timing circuit. EIT direct-reading decade scaler tubes are used.—Ransom Research, Box 382, San Pedro, Calif.

Lead shield for counter tube. Special lead shield for Bernstein-Ballentine counter tube is 4-in. d × 20-in. long. Shield has top door that completely encloses tube. Shield thickness is $1\frac{1}{2}$ in.—Radiological Service Co., 92-15 172 St., Jamaica 33, N. Y.

INDUSTRY NOTES

▶**Millipore Filter Corp.,** Watertown, Mass., has named **Richard Cotton** as technical director, in charge of research and development on fine-pore filter-membrane products.

▶**Atomic Research Laboratory** is now located at **10717 Venice Blvd., Los Angeles, Calif.** New site has four times the space of the former one.

▶**Nuclear Development Associates, Inc.,** White Plains, N. Y., will conduct reactor-irradiation studies of reactor components for clients. Serv-

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SHEET

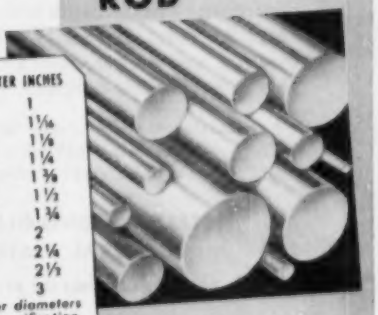
Thickness Inches	Nominal Size
1/16	12 x 12
3/32	18 x 18
1/8	24 x 24
3/16	36 x 36*
1/4	48 x 48*
3/8	
1/2 & Up	

* Can be furnished in 1/2 sheets

ROD

DIAMETER INCHES	
1/4	1
5/16	1 1/16
3/8	1 1/8
7/16	1 1/4
1/2	1 3/8
9/16	1 1/2
5/8	1 3/4
3/4	2
7/8	2 1/4
	2 1/2
	3

Other diameters on specification



TUBING

TYPICAL SIZES INCHES	
O. D.	I. D.
3/8	1/4
1/2	3/8
3/4	1/2
1	3/4
1 1/2	1
2 1/2	1 1/2
3	1 3/4

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CHEMICAL
Completely inert.

ELECTRICAL
Very high dielectric strength. Extremely low power factor.

THERMAL
Temperature range −300° to +500° F.

MECHANICAL
Strong, flexible, weather resistant.

LOW COEFFICIENT OF FRICTION
Absolutely non-stick.

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ice includes adapting test capsules, supervising tests, and transporting samples after irradiation.

▶**Isotopes Specialties Co.** has moved to larger quarters at **703 South Main St., Burbank, Calif.** Move was necessitated by expansion of company's line.

▶**Hallamore Manufacturing Co.,** Long Beach, Calif., producers of scintillometers, G-M counters, and other electronic devices, has been purchased by **The Siegler Corp.,** Centralia, Ill., and will now be known as **Hallamore Electronics Co.**

▶**Amperex Electronic Corp.,** Hicksville, N. Y. has appointed **Peter Janis** as chief engineer.

▶**Dian Laboratories, Inc.,** 611 Broadway, New York, N. Y. has opened an analogue computing center. Services are available on a rental basis.

▶**Beckman Instruments Inc.,** Fullerton, Calif., has purchased the **Liston-Becker Instrument Co.,** Springdale, Conn., makers of infrared gas analyzers, and specialized electronic amplifiers.

LITERATURE AVAILABLE

Flexible hose. Bulletins 40–44 and price list tell story of flexible hose and ducts for ventilation. 4 p. each. —The Flexaust Co., 100 Park Ave., New York 17, N. Y.

Flow meters. Publication 55-1074-222 shows features of electronic, mercury-less, flow meter. 12 p.—The Hays Corp., Michigan City, Ind.

Microfocus X-ray unit. Catalog describes X-ray unit with focal spot diameter of order of 0.04 mm. 12 p. —Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.

Radiation instruments. Just published catalog illustrates and describes line of laboratory radiation detectors and accessories, including liquid phosphor counters. 20 p.—Technical Measurement Corp., 140 State St., New Haven 11, Conn.

100-channel analyzer. Brochure describes PA-3 pulse-height analyzer with 100 channels. 4 p.—Pacific Electro-Nuclear Co., 8930 Lindblade St., Culver City, Calif.

Gamma radiography. Pamphlet explains principles, applications and

equipment of radioisotope radiography. Also available is a booklet on this company. 12 and 8 p.—Technical Operations Inc., 6 Schouler Ct., Arlington 74, Mass.

Micron-sized filter. Leaflet gives applications in atomic energy of micron-sized-pore filter, and price list shows related equipment.—Millipore Filter Corp., Watertown 72, Mass.

Numerical data printers. Two folders list six models of parallel-entry data printers; and four models of serial-entry printers. 6 p. each.—Electronic Div., Clary Corp., San Gabriel, Calif.

Borides. Catalog on refractory grains includes section on B_4C. Booklet on basic materials for industry includes section on available forms of B. 24 p. each.—Norton Co., Refractories Div., Worchester 6, Mass.

Investing in the atomic age. Brochure explains unusual investment problems caused by nucleonics. 4 p.—Science & Nuclear Distributors, 1500 Walnut St., Philadelphia 2, Pa.

Three-dimensional microscopes. Brochure tells how 3-D microscopes are used in industry and research laboratories. 38 p.—Bausch & Lomb Co., 635 St. Paul St., Rochester, N. Y.

Oscilloscopes and preamplifiers. Booklet contains descriptions and specifications of type 530 oscilloscopes and plug-in preamplifiers. 16 p.—Tektronix, Inc., Box 831, Portland 7, Ore.

Servomechanism components. Bulletin 362 gives specifications and characteristics for over 130 synchros, servo motors and related items. 16 p.—Norden-Ketay Corp., 555 Broadway, New York 12, N. Y.

Pulse test equipment. Four data sheets describe variable pulse generator, long-time-delay generator, and two pulse oscillators. 2 p. each.—Electro-Pulse Inc., 11811 Major St., Culver City, Calif.

Scintillation spectrometer. Data sheet IDS 10.16–19 shows RIDL automatic scintillation spectrometer for β- and γ-ray analysis. 2 p.—Minneapolis-Honeywell Regulator Co., Wayne and Windrim Aves., Philadelphia 44, Pa.

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LETTERS

Corrections

DEAR SIR:

Two corrections are necessary in the article "Nitrogen Fixation in a Nuclear Reactor," by L. H. Fuchs and myself (NU, March '55, p. 38).

Line 13 on p. 40, right column, should read 10^{-24} instead of 10^{24}.

Page 40, right column, line 33, *et seq.*: The argument of the density-of-paths function here and in the figure and table should, of course, be the same. For $p > 2$, it is given incorrectly and should be

$$N(p) = (\tfrac{4}{3}\pi p)[2\mathbf{B}(2/p) - \mathbf{E}(2/p)]$$

The fraction of energy expended in the gas should be

$$(1/0.59)\int_0^{\lambda} N(p)E(p)dp + \int_{\lambda}^{\infty} N(p)dp$$

where λ is the range of the proton.

—WILLIAM PRIMAK
Chemistry Division
Argonne National Laboratory
Lemont, Illinois

Radiation Effects on the Retina

DEAR SIR:

In the April issue, there was reported under "Technical Advances" an instance of a whole organism responding to stimulation by X-rays. The following historical note was added: "in 1909 Helmholtz reported response to X-rays by the human eye. Mechanism there is probably visual detection of induced fluorescence in the eye itself." Allow me to correct and expand on that note.

Brandes and Dorn in 1896 were the first to report that X-irradiation of the human eye aroused a sensation of light. Nearly 200 papers have since been published on the subject.* In one of the latest, Bornschein, Pape, and Zakovsky report that under optimal conditions a ½-mr dose of X-rays is sufficient to arouse a sensation of light.

A recent study† confirms the finding of Newell and Borley in 1941 that induced fluorescence is *not* the mechanism by which X-rays affect the retina. In this study were compared the energies of threshold-visibility doses of light and X-rays and of visual-purple-bleaching doses of light and X-rays. The findings were consistent with the hy-

pothesis that X-rays produce a light sensation by direct effect on the photochemicals of the retina.

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—Leo E. Lipetz
Department of Ophthalmology
College of Medicine
The Ohio State University
Columbus, Ohio

* L. E. Lipetz. Review of the literature on visibility of X-rays and radium rays, to be published.

† L. E. Lipetz. An electrophysiological study of some properties of the vertebrate retina, thesis, University of California, Berkeley (1953).

‡ L. E. Lipetz. The structure responsible for action potential spike in the frog's retina, in manuscript.

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NEWSMAKERS

M. A. Schultz, Westinghouse Electric Corp., has been elected chairman for the coming year of the administrative committee of the professional group on nuclear science of the Institute of Radio Engineers.

Frank K. Pittman has been appointed deputy director of AEC's division of licensing. Since April, 1954, he has served in a similar capacity in the production division.

J. Emmett Maider, Jr., has been named by General Electric Co. to be manager of its Commonwealth Edison project. He is succeeded as manager of manufacturing at Hanford by **W. K. MacCready,** formerly manager of the reactor section. **Robert S. Bell,** formerly manager of the separations section in the manufacturing department, is the new manager of the reactor section. He is succeeded by **J. Hugh Warren,** superintendent of the reactor operations subsection.

Charles H. Weaver, who has directed Westinghouse Electric's atomic power division since its organization in 1948, has been elected a vice president of the Corporation; he will be responsible for all the company's nuclear power activities. He will be succeeded by **John W. Simpson,** who has been manager of the PWR project.

RAW MATERIALS

CHILE: arranges for uranium production with U. S. technical assistance. Following current talks on exploration and development between the U. S. Embassy in Santiago and Minister of Mines, it is said that the U. S. will purchase uranium at the same prices paid U. S. producers. Two mineral samples have shown uranium contents of 0.55 and 0.60%.

MOZAMBIQUE: surveys mineral deposits. The Swedish company Bolidens Gruv. AB has staked several uranium ore claims and has applied for exclusive prospecting rights in the Tete district and for a mineral concession in Angola.

JORDAN: discovers uranium deposits. Uranium has been found in the phosphate area of Hassa village in Jordan's southern district. Quantity and percentages are not yet known.

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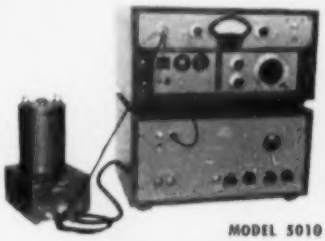

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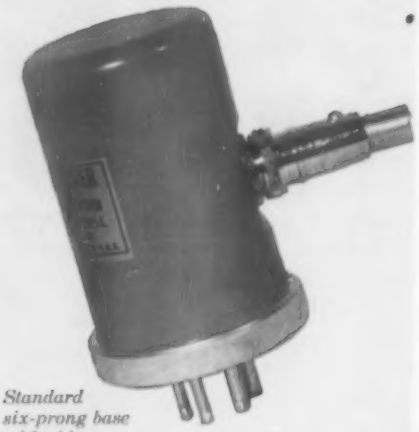

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